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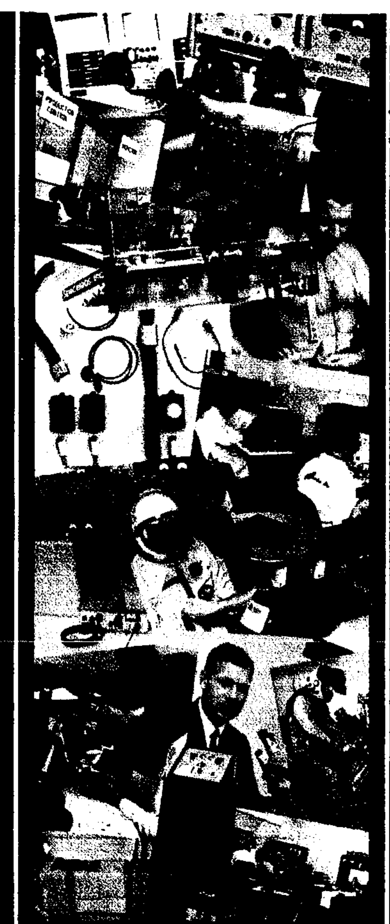
FINAL REPORT

CONTRACT NO. NAS 9-4614

16 CHANNEL MICROMINATURE FM

TELEMETRY SYSTEM

Spacelabs, Inc.



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REPORT NUMBER SR68-1054

FINAL REPORT

CONTRACT NO. NAS 9-4614

16 CHANNEL MICROMINATURE FM TELEMETRY SYSTEM

PREPARED FOR:

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8 OCTOBER 1968

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SECTION 1

INTRODUCTION

This document constitutes a Final Report of the work performed by Spacelabs, Inc. under Contract NAS 9-4614. The contract effort involved the design, development and production of two 16-Channel FM Telemetry Systems. The contract was awarded on June 17, 1965 and delivery of equipment to NASA was final on September 9, 1968.

The final equipment produced under this contract is manufactured by Sonex, Inc. under subcontract to Spacelabs, Inc. This Final Report does not include a detailed description of the final system as manufactured by Sonex, Inc. due to the fact that much of the technical detail of the ultimate system is considered proprietary by Sonex, Inc. Technical details of the final system will be delivered directly to the Contracting Agency by Sonex, Inc.

This program underwent several significant changes as a result of major technical problems. To aid in establishing overall perspective, a brief summary of the program follows this Introduction.

To provide the reader with a more detailed overview of the program, a tabulated program chronology immediately follows the Summary. This chronological history of the program is intended to serve as a historical narrative, emphasizing only the program highlights. Specific details of the program are included in the section covering operation and in the Appendices.

SECTION 2

SUMMARY

Work on the contract commenced with the development of Spacelabs' proposed system. Due to insurmountable technical difficulties, the basic design concept was changed approximately eight weeks after effort on the contract began. A new design concept proved feasible and after development, manufacturing drawings were released to a microcircuit subcontractor for fabrication. It was subsequently determined that an advancement in the state-of-the-art relative to microcircuit component specifications would be necessary before the design could be practically, if at all, produced.

It was jointly determined by NASA and Spacelabs that a further revision of the program effort was necessary. As a consequence, Spacelabs subcontracted to Sonex, Inc., for delivery of equipment under the terms, conditions and requirements of a major modification to the Contract Statement of Work. Sonex, Inc. successfully developed and delivered the required equipment. The program was thus completed and closed out.

SECTION 3

PROGRAM CHRONOLOGY

Spacelabs received contract award on June 17, 1965. A Program Plan was organized which insured that the entire contractual requirements would be properly monitored, and which would facilitate an intensive effort in those areas of the system which represented advances in the state-of-the-art and would require particular attention.

June - July 1965

During the first month of the program, major effort was directed toward the design and test of the major system functional blocks. Work on the composite signal amplifier was approximately 80% complete and breadboard test data indicated that all specifications would be met.

By the end of the first month, the electrical design for the mixer amplifier had been completed, and all that remained was the final design and testing of the isolation transformer.

July - August 1965

Work toward the final development of the Voltage Controlled Oscillator was progressing very well, and problems which subsequently occurred were not as yet anticipated. The conceptual design of the power supply had been completed and delivery of prototype transformers was expected in the very near future. Work toward the completion of the two-point calibrator was progressing according to schedule and no problems were anticipated.

August - September 1965

Work in all phases of the program continued with special emphasis on the selection of specific components, such as integrated circuits, and the selection of a subcontractor for the thin-filming fabrication of the system components.

A design modification to the two-point calibrator was necessary in the interest of packaging and reliability. A problem relative to the modulation of the VCO was encountered. The apparent solution to the problem involved the disadvantage of increased circuit complexity and as a result simpler methods were being investigated.

Major technical problems with the modulation scheme for the Twin-Tee oscillator required a change in the basic oscillator concept. This resulted in the need for a contract delivery extension of two months.

The new VCO oscillator, termed "Dual 90," performed very well during preliminary testing and indications were that it would meet the performance requirements.

Detailed information on this oscillator, including its theory of operation, is included in Section 6.

September - October 1965

Work continued on the development of the entire system with special emphasis on the VCO. At this point, it appeared that all specification requirements would be met and no major problems were anticipated.

October - November 1965

The circuit designs for the VCO were completed and final testing was being conducted. Preliminary test data showed that the VCO would perform to the specification requirements.

Bunker-Ramo Corporation was selected as the subcontractor for the fabrication of the thin-film circuit modules. Preparation of a final subcontract was underway and negotiations were in progress.

November - December 1965

Design of the composite signal amplifier and mixer circuits was completed. Testing of the VCO continued, and some modification of the AGC circuit was initiated to improve distortion and amplitude modulation.

The system package layouts were started and work was progressing on the contract as a whole in a relatively comfortable manner.

December 1965 - January 1966

A subcontract for fabrication of the microcircuits was let to the Bunker-Ramo Corporation early in December.

Continued testing of the VCO indicated that additional problems existed. Specifically, the high frequency VCO channels exhibited extraneous phase shift in the phase shift amplifiers, with the result that the VCO output contained excessive distortion and amplitude modulation. These problems were subsequently solved by a modification.

During the latter portion of this period, diode circuit components deposited on a thin-film substrate were received from the Bunker-Ramo Corporation for incorporation into the breadboard circuitry and subsequent evaluation. The results of these tests indicated that the microcircuited components were behaving as predicted.

Procurement of long-lead items was initiated. Work on the program was being accomplished at a high rate of progress.

January - February 1966

Difficulty encountered in the fabrication of the thin-film microcircuits on the part of the Bunker-Ramo Corporation forced an overall program schedule slippage. Additionally, an increase in the VCO module dimension was required which resulted in a rather high probability that the specified system volume might not be met.

Work on the remainder of the system continued, including the preparation of a Test Plan and Acceptance Test Procedures.

February - March 1966

Continued difficulty with the component packaging was experienced and it became apparent that the required overall system volume would be exceeded.

The thin-film microcircuit version of the mixer amplifier was completed and delivered to Spacelabs for evaluation. Performance was very satisfactory and met the requirements of the Contract Statement of Work as a component.

Testing of a complete breadboard system was progressing and the system operation was performing as required.

March - April 1966

Spacelabs was notified by the Bunker-Ramo Corporation that they would be unable to meet their presently scheduled delivery commitments. A schedule slippage of approximately four weeks was estimated.

Substantial technical problems with the first engineering microcircuited VCO resulted in further schedule slippages. At this point the thin-film substrates had been completed and were being assembled. Efforts were made to accelerate the program and to provide additional technical effort in those areas where difficulty was being encountered.

May - June 1966

The modulator portion of the engineering model microcircuited VCO was completed and preliminary evaluation initiated.

The System Test Plan was completed and ready for delivery to NASA for review.

June - July 1966

Testing of the VCO engineering model indicated that satisfactory operation was being achieved over a sufficiently wide frequency range that no difficulty in this respect was anticipated in the final system.

Fabrication of system components not requiring thin-film techniques was initiated.

July - August 1966

A thin-film model of the oscillator portion of the VCO was completed and preliminary tests initiated. Preliminary results indicated that there was some technical difficulties with the AGC circuit.

Packaging design of the overall system was, at this point in time, essentially completed and a thorough design analysis was in progress.

August 1966 - January 1967

While work on the remainder of the contract progressed, particular attention was devoted to the VCO and the associated fabrication problems. Continued difficulties made it doubtful that the VCO could be fabricated without an advancement in the present state-of-the-art. As a result of identification of major problems with the program in general, a meeting between Spacelabs and the Bunker-Ramo Corporation was conducted to determine the status of the program, the probability of successful solution, and estimated delivery dates.

At this meeting it was decided that the problems should be jointly presented to NASA personnel in a conference at the Manned Spacecraft Center. The result of that meeting was a decision that Spacelabs should cease current sub-contract activity and investigate the possibility of selecting another subcontractor who would be capable of manufacturing a revised system requiring state-of-the-art technology.

Sonex, Inc. was subsequently chosen as the subcontractor. The system technical requirements and the program schedule requirements were modified and work on the revised 16-Channel FM Telemetry System was initiated at Sonex, Inc.

February - May 1967

Work on the system by Sonex, Inc. was progressing faborably until effort was diverted to other NASA work under contract to Sonex which was given higher priority by NASA. Although work continued on the contract, some schedule slippages were experienced.

By March of 1967, the mechanical system prototype package has been completed. Technical difficulties in the electrical areas were encountered and solved. While most of the electrical design was complete at this time, a small percentage remained and was scheduled for completion in April.

June - August 1967

By June, the prototype testing was nearing completion and system documentation necessary for production release had been completed. Work toward the fabrication of the first production prototype continued through June. Testing of the prototype system was completed in July and production of the final units initiated.

September - November 1967

By September of 1967, most of the required VCO's had been built and tested, and other system components, while exhibiting some problems, were progressing toward completion.

During October, Sonex assembled the first system but during acceptance test, it was discovered that certain parameters in the VCO Channels were out of specification. Consequently, the system had to be disassembled to correct the discrepancy.

In November, the first system was corrected and delivered to NASA for final checkout and acceptance.

December - March 1968

Throughout the month of December, NASA conducted extensive testing on the system and on January 10, the system was rejected and returned to Sonex to correct a VCO failure.

Sonex disassembled the system and proceeded to replace the VCO. While Sonex was in the process of repairing this system they encountered numerable problems with the power supply. As a result of these problems, production on the second system was halted until the problems could be resolved.

On March 15 the first system was corrected and shipped to NASA for checkout.

April - June 1968

Sonex continued with the production of the second system, but was still having extensive technical problems with the power supply. In June, Sonex requested that the input power requirements be relaxed from 28 VDC to 10 VDC. Spacelabs contacted NASA concerning this deviation, and subsequently NASA granted this deviation.

July - September 1968

During this period, Sonex was proceeding to complete the second system, but was encountering delays because their subcontractor, Powercube, Corporation was having difficulty manufacturing the power-supply.

Upon receipt of the power supply, Sonex assembled the system and shipped it to NASA for final acceptance.

SECTION 4

MAJOR PROGRAM PROBLEMS

Introduction

To provide a clear understanding of the major problems encountered during the course of the program, a detailed technical discussion is presented in this section.

Twin-Tee Oscillator

The performance of the Twin-Tee oscillator itself exceeded the requirements of the specification. The problem which occurred with the overall VCO, which ultimately required another approach, was the modulator circuitry.

Tests of the Twin-Tee oscillator showed that the output contained considerable signal at the modulation frequency. This was due to the modulating voltage appearing across the modulation diodes. Because modulation frequencies as high as 15% of center frequency would be encountered, it is impossible to separate the oscillator and modulation frequencies by filtering. To eliminate these frequencies, each diode string (of which there are three) would have to be replaced with a balanced diode bridge. This would make the unit so complex as not to be feasible within the package configuration.

Although it only requires a few sentences to describe the nature of this problem and to indicate the limitations, the amount of work leading to this conclusion and the impact on the program was considerable.

Microcircuits

After several months of unsuccessful attempts to produce a thin-film version for the VCO, the Bunker-Ramo Corporation concluded that the circuit was impossible to build without an advance in the state-of-the-art.

At the time the contract was negotiated, Bunker-Ramo thought that the problems presented by the circuit, though admittedly difficult, could be solved by the straightforward application of existing technology, since most of the recognized problems had been solved individually in the fabrication of other circuits. As work progressed, it became apparent that much more development effort would be required in order to adapt these solutions to the VCO problems than had been expected. Although many of the problems which were encountered had been solved, the probability of solving the remainder of the problems and therefore producing a successful microcircuited VCO was practically non-existent.

In reducing the VCO to a microcircuit package, three principal problems were encountered. These were, namely: complexity, component density, and precision.

<u>Complexity</u>

In determining the manufacturing and functional complexity of this specific device, several factors have to be considered. Certainly one of these is the absolute number of components. Secondly, the general type of circuit has to be considered, i.e., digital or analog, a.c. coupled or d.c. coupled, active or passive, etc. The less complex circuitry is a digital circuit, direct coupled with or without active components. The next most difficult, from the standpoint of function and manufacturing, are a.c. coupled, analog circuits. The most difficult are the direct coupled, linear circuits.

In the case of the VCO, not only is the component count very large, but it represents the most difficult from the standpoint of circuit function and fabrication techniques, i.e., it is a direct coupled, analog,linear circuit. For reference purposes, the basic complexity of the circuit is indicated by the fact that there are 128 individual components, which include 71 resistors, 28 bipolar transistors - 10 of which are matched, 17 diodes, 4 field effect transistors, and 7 capacitors - 2 of which are precision.

The convergence of these various problems, together with that of the package size requirements, constituted a problem which was impossible to solve without an advancement in the state-of-the-art.

Component Density

The requirement for minimum volume for the VCO necessitated that the entire circuit be on two substrates, that chip-type active components be used, and that capacitors with minimum protective covering be used. The normal requirements to minimize unwanted mutual coupling and to isolate temperature sensitive circuit elements from heat sources while retaining maximum component density, resulted in a very difficult layout problem. The layout problem was further complicated by the fact that many of the resistors had to be constructed to allow for manual selection of one of several values during assembly. The extensive use of chip components required the use of approximately 135 thermal compression bonds in 2.5 square inches to connect to the chips, and, of course, the chips were bonded to the substrate.

The high density, the large number of manual operations, and the use of fragile components had made the occurrence of fabrication errors unusually high. Testing and trouble-shooting was unusually difficult because: (1) the high density, (2) the circuit was largely d. c. coupled and had complicated interactions, and (3) many of the problems were subtle and could not be detected until the entire VCO circuit was being tested for precision or temperature stability.

Finally, once the problems had been isolated, rework proved extremely difficult and there was a high probability of permanent damage to the circuit. The expected yield due to the complexities and difficulties reiterated was extremely low.

Precision

The VCO called for a number of high precision resistors with matched and controlled temperature coefficients. In addition, the temperature coefficients of two precision capacitors had to be compensated by the temperature coefficients of two resistors to maintain a controlled time constant over a wide range of temperature. Unfortunately, the temperature coefficient of the capacitors had been found to vary from unit-to-unit. For example, the TCR of the precision capacitors used in the VCO had been found to vary from -30 ppm to +30 ppm. Since the TCR of each capacitor had to be measured and selected to at least within $\pm$ 2.5 ppm. This was a severe restriction on part interchangeability and replacement in case of part breakage.

Several of the transistors required close matching over a wide temperature range. A great deal of difficulty had been experienced, particularly with the field effect transistors in retaining the required characteristics after the chips were bonded to the substrate.

As a consequence of these problems, it became apparent that the precision necessary for operation to the specification requirements in all probability could not be obtained.

SECTION 5

DESCRIPTION OF PROPOSED SYSTEM

Introduction

In response to RFP No. BG731-38-5-534P describing the requirements for the Design, Development, Manufacture and Test of a Miniaturized 16-Channel FM Telemetry System, Spacelabs, Inc. proposed a system which incorporated a unique Voltage Controlled Oscillator representing a significant advance in the state-of-the-art in FM Telemetry.

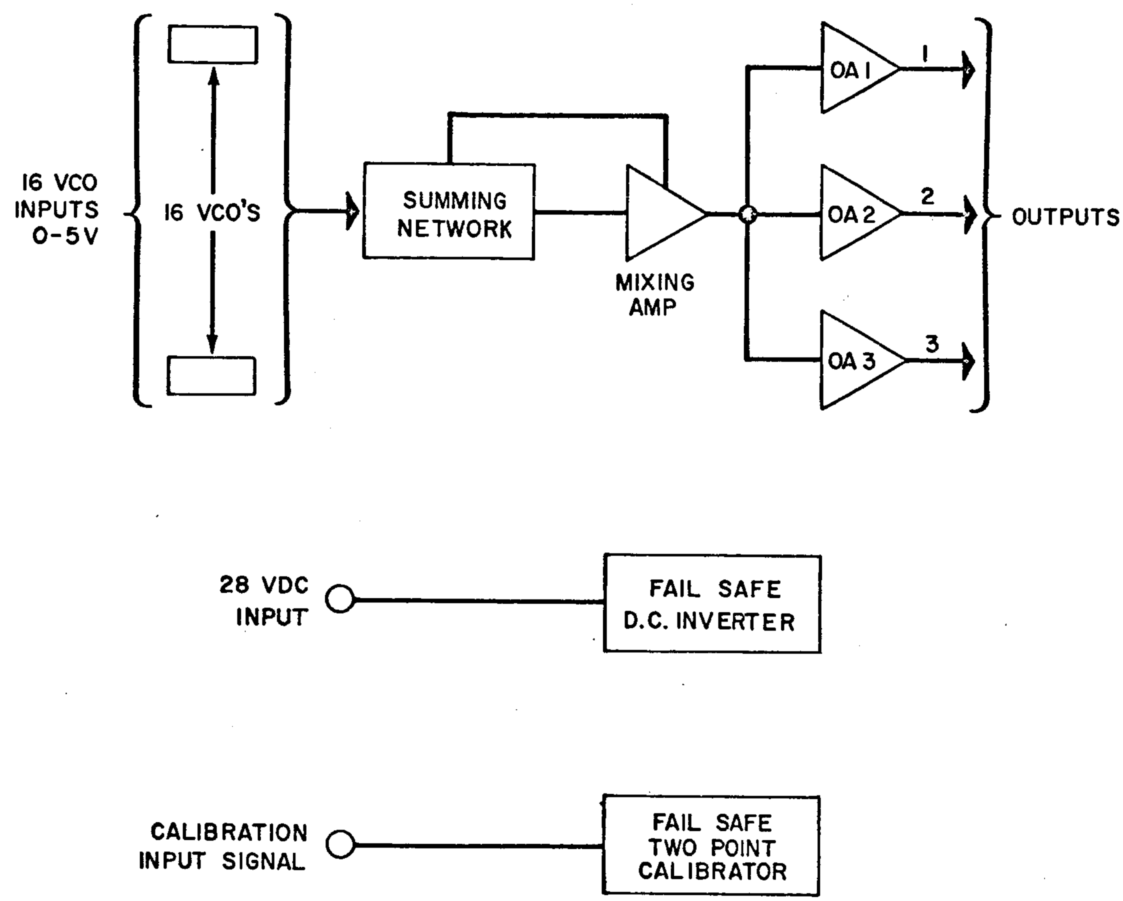
In addition to a well documented and fully detailed description of the proposed Voltage Controlled Oscillator, the entire FM Telemetry System was carefully described and a sound conceptual approach proposed.

System Description

The proposed system consisted of the 16 channels of data information, a power supply and a two-point calibrator. The system components were arranged in a standard manner with the 16 VCO's terminated in a summing network and mixing amplifier, the output of which supplied drive power to three output amplifiers. The proposed FM Telemetry System block diagram is shown in Figure 1.

System Components

Each functional requirement of the FM Telemetry System was analyzed with respect to the system requirement and the available technical approaches for



FM TELEMETRY SYSTEM
BLOCK DIAGRAM

FIGURE 1

the implementation of the particular function. The specific selection criteria and a detailed comparison are available to the interested reader in Spacelabs' Proposal No. 1094.

Voltage Controlled Oscillator

A review of Voltage Controlled Oscillators was included which covered the specific characteristics and operating performance of each. These characteristics were compared with the unique Voltage Controlled Oscillator which had been partially developed and tested by Spacelabs. It was concluded that the overall characteristics of Spacelabs' VCO were superior to any available.

The proposed Voltage Controlled Oscillator was a voltage controlled parallel-Tee which, during performance testing at Spacelabs, exhibited performance which exceeded all the required specifications by a significant margin. The stability and performance of the parallel-Tee oscillator was related to the logarithmic properties of semi-conductors and were utilized in such a way to provide for automatic self-correction of their own temperature characteristics.

The VCO employed a unique technique for modulating the center frequency. This technique had demonstrated exceptional linearity over several decades of frequency. The modulator consists of a series of diodes and associated circuitry which exhibits a temperature invariant inverse relationship between the impedance of the network and the input voltage to it.

The proposal included analysis and the results of actual tests which were conducted on actual models of the Voltage Controlled Oscillator and modulator system.

Signal Mixer

The proposed signal mixing network was a standard resistance summation network and did not represent any deviation from that normally incorporated in telemetry systems.

Composite Signal Amplifier

The composite signal amplifier was proposed to be designed specifically to the RFP requirements. It featured a high resistance input, a highly reliable minuteman rated operational amplifier, and the necessary balanced output transformer required of the floating output system.

Two-Point Voltage Calibrator

To provide the required accuracy and stability, a two-point calibrator was proposed which consisted essentially of a precision power converter. Control of the calibrator was accomplished through the use of an isolating transformer, while stability was assured by employing a temperature compensated Zener diode.

Due to the specific requirements of the RFP relative to the two-point calibrator, Spacelabs proposed the foregoing as a specifically designed and developed component.

Power Supply

The proposed power supply was specifically configured to meet the overall requirements of the FM Telemetry System and the specific requirements of the data processing components. Particular attention was paid to the suppression of spurious responses and EMI problems. Additionally, it incorporated a fail-safe feature as required by the RFP.

Package

A packaging concept was proposed which incorporated individual subsystem components interconnected by means of a matrix board. The case provided a hermetic seal and was proposed to be constructed of magnesium and be gold-plated in compliance with the specific requirements of the RFP. Moisture seals, hermetically sealed connectors and "O-ring" case seals were proposed to insure a completely moisture-proof package.

SECTION 6

DESCRIPTION OF SPACELABS TELEMETRY SYSTEM

General System Considerations

The packaging concept was derived from consideration of several pertinent specific requirements of the Contract Statement of Work relative to packaging dimensions and structural concept, the environmental requirements, the end item use, and the manufacturing and test of the system.

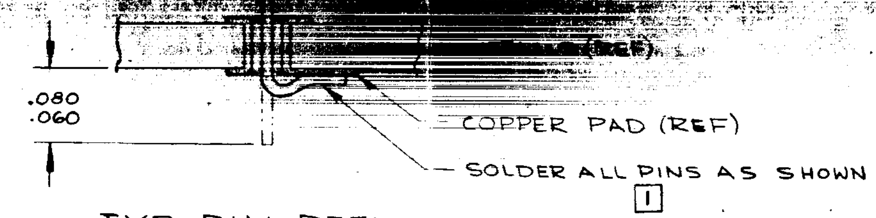
Basically the system is housed in a rectangular assembly which measures approximately 4.4 x 2.6 x 1.2 inches, the 1.2-inch dimension being the height of the unit. All of the components comprising the telemetry system are manufactured as individual components and are subjected to an individual acceptance test plan prior to incorporation in the final system assembly. The 16 VCO's comprise over 50% of the internal package volume and are arranged adjacent to each other along the maximum dimension of the final assembly as shown in the system board subassembly, Figure 1. The remainder of the system components are arranged in the remaining volume in such a manner as to minimize intermodule connection requirements and to isolate the power supply to as great an extent as possible from the critical system components, primarily the voltage controlled oscillators.

As noted in the drawing, the power supply module is located close to the input/output connector. This was in part intended to minimize the length of the power conductors necessary inside the module between the connector and the power supply itself. Normally EMI requirements which include conducted ratio frequency interference necessitate the use of filters at the connector interface.

FOLDOUT FRAME 1

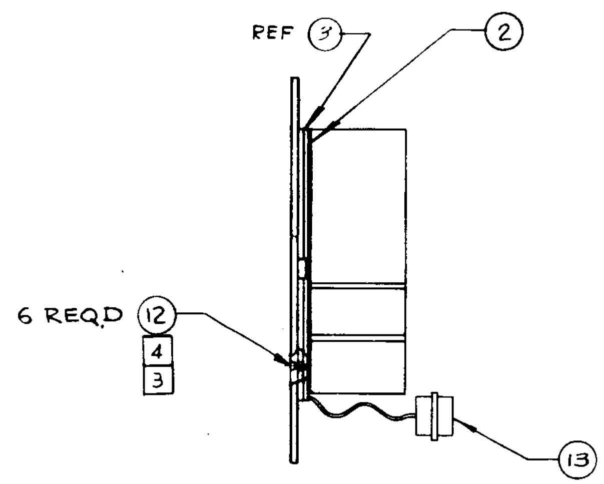
FOLDOUT FRAME 2

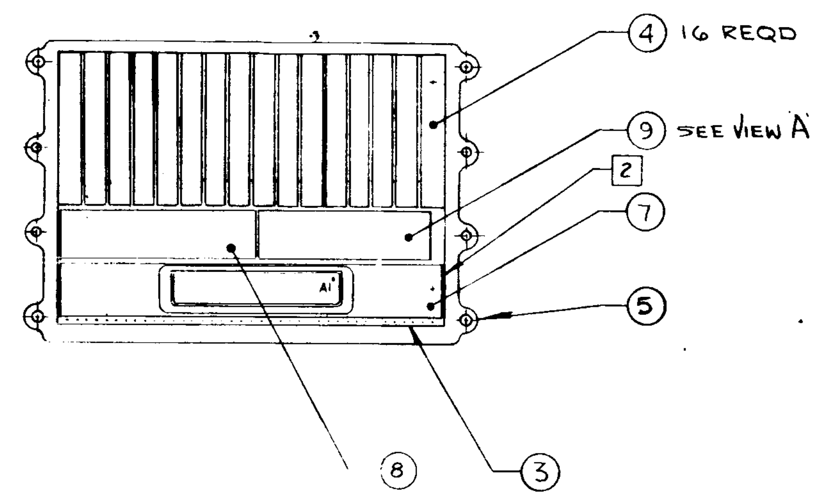
REVISIONS					
LTR	ZONE	DESCRIPTION	MFG EFF	PART ASSY	APPROVAL & DATE
		CONTROLLED RELEASE			7-1-66

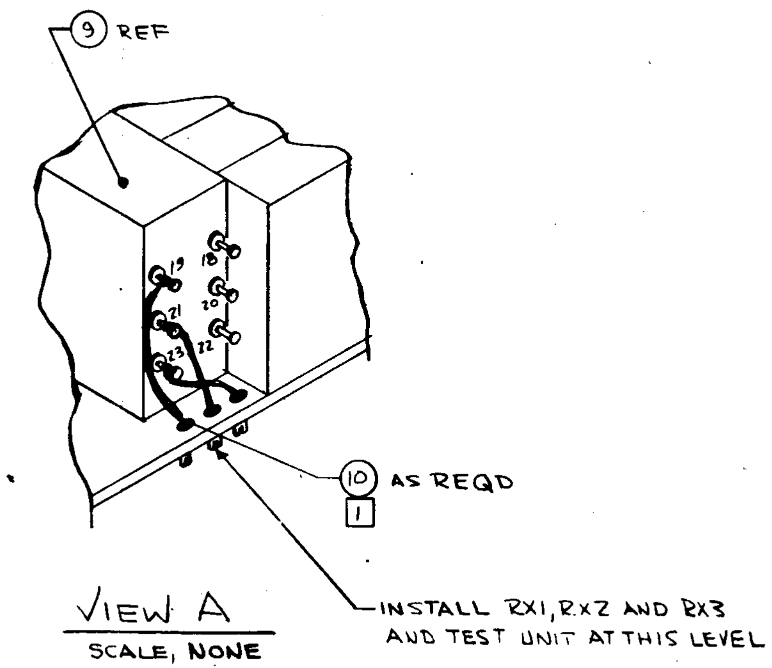


TYP PIN DETAIL

SCALE 10/1







VIEW A

SCALE, NONE

FIGURE 1

QTY PER ASSY	ITEM	PART NO	DESCRIPTION	MATL	MATL SPEC
AR	15		LOCKING COMPOUND	LOCTITE OR EQUIV.	
AR	14		SOLDER, Ag 5.5 WARP 2		QQ-S-571
1	13	104532	CONNECTOR ASSY		
6	12		SCREW, FLAT HD	82°, 4-40 x .12 LG	
AR	11		SOLDER, Sn 63 WARP2		QQ-S-571
AR	10		WIRE, INSULATED		26 GAGE
1	9	104365-1	PRE-EMPHASIS MODULE		
1	8	103875-1	CAL & REG MODULE		
1	7	104108-1	POWER SUPPLY MODULE		
1	5	104105-1	PLATE, BASE		
16	4	103866-1	V.C.O. MODULE		
1	3	104099-1	BOARD		
1	2	104368-1	INSULATOR, MODULE		
-	1	-1	ASSY		

LIST OF MATERIAL

104100

DRAFT F. Boyer 6-30-66
DESIGNER E. Boyer 6-30-66

BOARD-SUBASSY, TELEMETRY

Spacelabs, Inc.
15521 LANARK ST.
VAN NUYS, CALIFORNIA

XX104358

SCALE 1/1 SHEET 1 OF 1

D

4 TORQUE ITEM 12 TO 3-5 IN. OZ.
3 APPLY ITEM 15 TO ITEM 12

2 SOLDER ITEM 7 TO ITEM 3 PER MIL-S-6872 USING ITEM 14.
1 ALL SOLDERING PER MIL-S-6872 USING ITEM 11

NOTES: UNLESS OTHERWISE SPECIFIED

Limited packaging volume precluded this possibility, however, and the precautions reiterated above were incorporated. Careful consideration in this particular area resulted in a fairly high confidence that conducted RF would not be a problem.

The in-line arrangement of the VCO's permitted the most orderly layout of the master interconnection board and further insured the shortest length interconnecting conductors. The potential problem of interchannel interference or cross-talk was given considerable attention and it was felt that the final layout, all factors considered, would insure the highest probability of minimum interchannel interference.

Power dissipation in the power supply module was a problem of particular concern in that the environmental analysis indicated that power dissipation would be fairly well concentrated, and unless paths of lower thermal conductivity to the baseplate were insured, there might well be a problem with excessive internal hot spots. Specific means of conducting heat from the power supply module directly to the housing baseplate by means of a specifically designed grounding bus were considered and planned for incorporation as an added precautionary measure. The results of the preliminary environmental analysis also indicated that the theoretical temperature rise within the module could be reduced significantly by increasing the thermal conductivity across the interface between the package cover and baseplate. The material which would most readily affect this increase in thermal conductivity was aluminum. Analysis of this material as a baseplate from the standpoint of vibration, shock, etc., indicated that it would indeed be acceptable.

The results of the environmental analysis played a large role in the selection of the encapsulating material. While weight and precured viscosity were extremely important factors relative to the system requirements and the manufacturing requirements, respectively, the damping characteristics of the encapsulant were vital. The environmental analysis shows how the structural properties of the encapsulant affect the overall damping factor of the system, and thus its performance and reliability under the required environmental stresses. Important in this problem was the degree of compressive and tensile stresses imposed on the master interconnection board and the module interconnecting pins. Without proper precaution in this area, material fatigue would substantially reduce the trouble-free operating life of the system.

Voltage Controlled Oscillator

The VCO consists of an RC oscillator, a modulator and an automatic gain control circuit. During the development of this component, the RC oscillator underwent several modifications as a result of efforts to simplify the manufacturing problem and to reduce the number of components in an effort to increase reliability. While the actual configuration changed slightly from some of the reference material included in this report, the basic operation and theory remained the same.

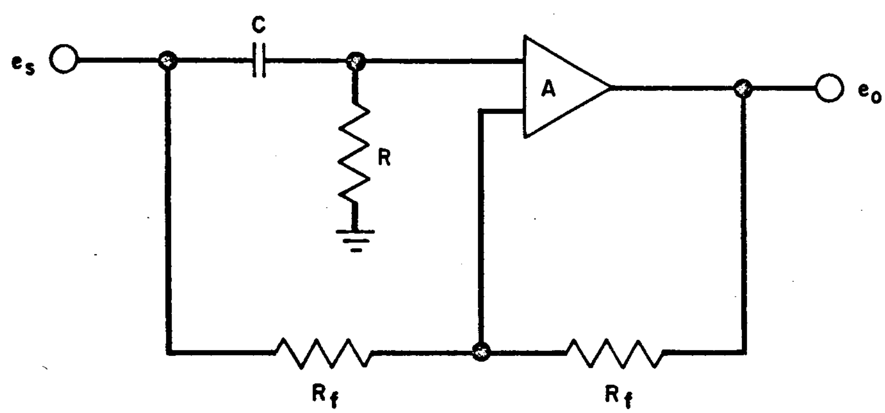
The basic circuit of the Dual-90 oscillator is a constant amplitude phase shifter. The basic circuit is shown in Figure 2.

For a phase shifter of this type the transfer function is:

$$\frac{e_{out}}{e_{in}} = \frac{TS - 1}{TS + 1}$$

Where:

$$T = RC$$



PHASE SHIFTER

FIGURE 2

An interesting property of this phase shifter is that the output amplitude is always constant regardless of the amount of phase shift. This can easily be shown by substituting $S = j\omega$ and solving.

If two of these phase shifters are connected in series and the output of the second phase shifter is inverted and fed back to the input of the first, as shown in Figure 3, an oscillator results.

The open loop transfer function of this system is:

$$\frac{e_o}{e_{in}} = \left(\frac{TS - 1}{TS + 1}\right)^2 \qquad (1)$$

If the loop gain is controlled by one AGC circuit so the amplifiers all operate in their linear regions, the output will be a low distortion sine wave.

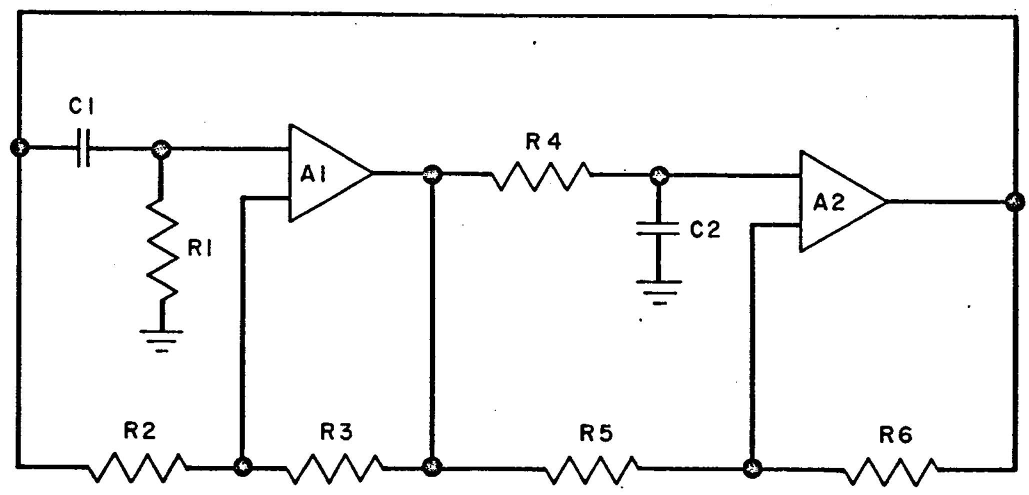
The frequency of this oscillator is primarily determined by the value of the RC time constant, so long as the phase shift in the amplifiers is small.

If this oscillator is modulated by bypassing some of the signal around one of the phase shifters, a new transfer function results:

$$\frac{e_o}{e_{in}} = \left(\frac{TS - 1}{TS + 1}\right)^2 + K\,e_m \left(\frac{TS - 1}{TS + 1}\right) \qquad (2)$$

Since 180° phase shift is needed for oscillation, the frequency can be calculated by substituting $S = j\omega$ and equating the imaginary part to zero. This yields:

$$\omega = \frac{1}{T} \quad \frac{2 - Ke_m}{2 + Ke_m} \qquad (3)$$



OSCILLATOR

FIGURE 3

When:

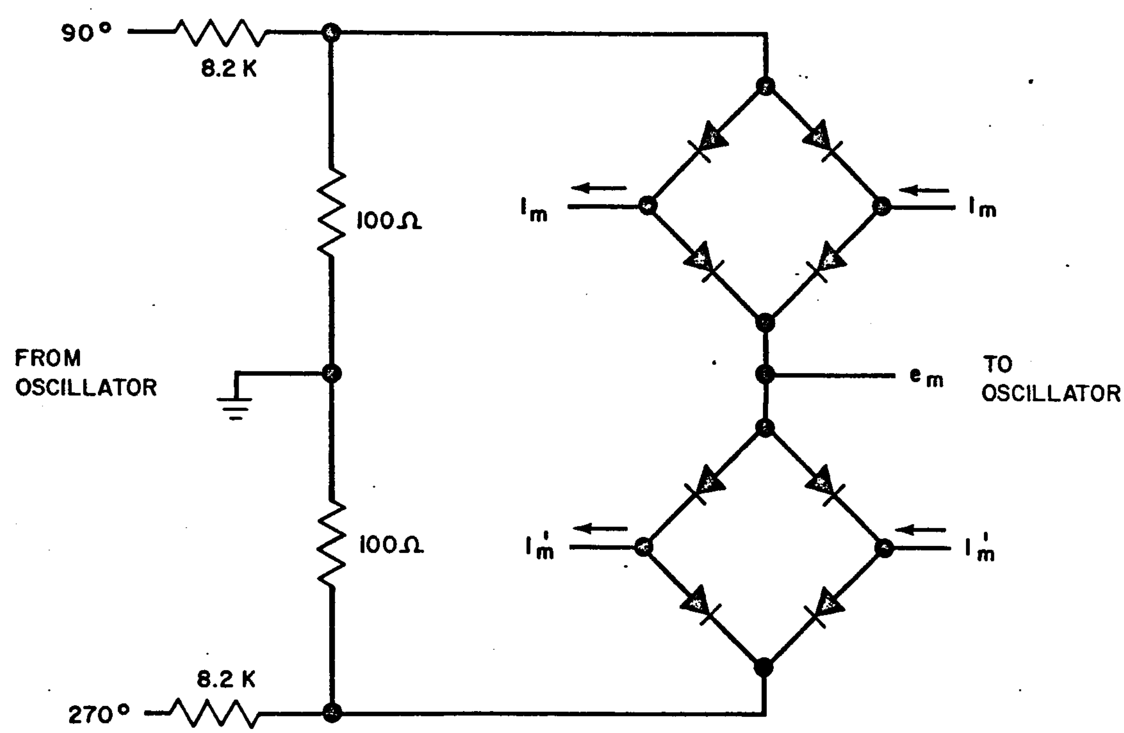
$T \quad = RC$

$Ke_m \quad$ = Modulation

$\omega \quad$ = Oscillation frequency in rad/sec

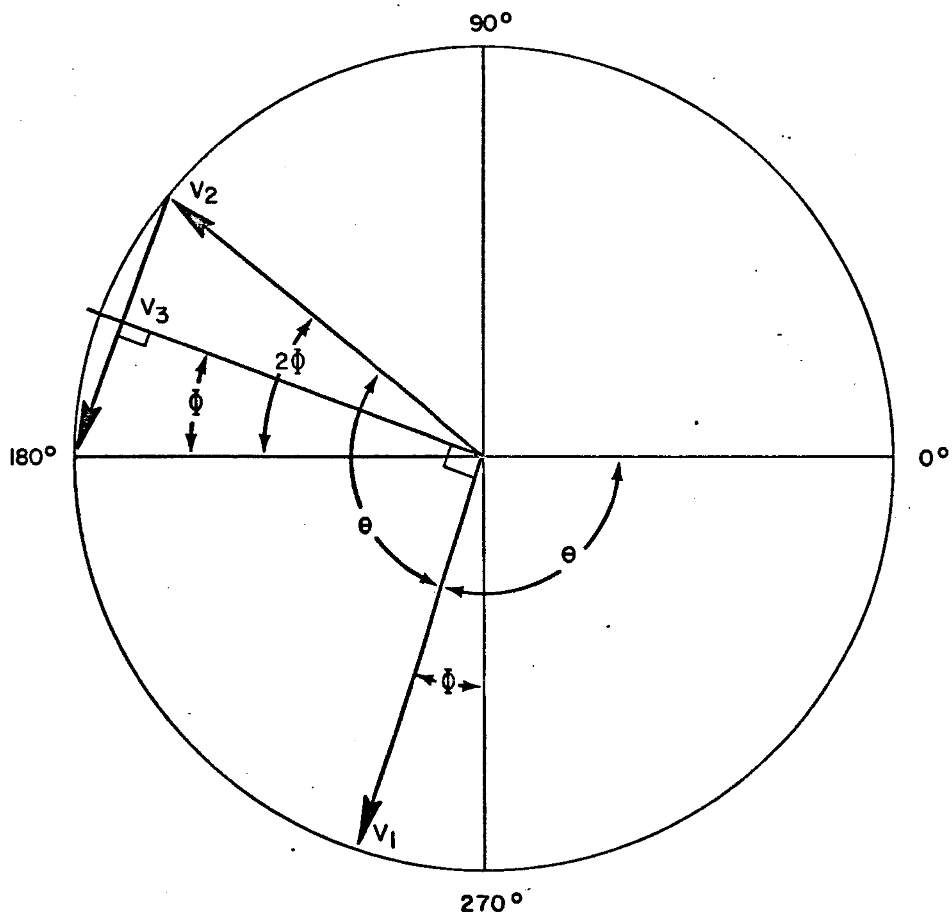
The frequency versus modulation voltage is non-linear as shown by Equation (3). However, if a diode bridge modulator is used, where the diodes are driven from current sources, the non-linearity of the modulator can be matched to the non-linearity of the oscillator to produce an almost perfectly linear VCO. A diagram of such a modulator is shown in Figure 4.

The fact that the transfer function shown in Equation (2) has constant amplitude is best shown vectorally as in Figure 5. Assume some modulation voltage is added in, as shown by V_3. The phase shift of each phase is now not 90°, but some new angle $\theta = 90° + \Phi$ and the second phase shifter output is shifted 2θ. Modulation voltage (V_3) must be applied to bring the resultant phase angle from 2θ to 180° or 2Φ. Since the angle of V_3 equals V_1, the line drawn bisecting the angle between V_2 and the axis is perpendicular to V_3, hence the triangle formed by V_2, V_3 and the 180° axis is isosceles and the resultant vector is always of the same length as V_2 and V_3. Hence there is no change in gain when modulation is applied.



MODULATOR

FIGURE 4



V_1 = OUTPUT OF 1st PHASE SHIFTER

V_2 = OUTPUT OF 2nd PHASE SHIFTER

V_3 = MODULATION VOLTAGE

PHASOR DIAGRAM

FIGURE 5

The modulator which was described briefly in the foregoing text generates a current at the oscillator frequency, the magnitude of which is proportional to the modulating signal. The diode quad modulator can be considered an analog multiplier since its output is the product of an input signal at the oscillator frequency and the magnitude of the modulating signal. As described above, it exhibits non-linear characteristics which serves to negate the opposite non-linear characteristics of the effect of modulating the phase shift oscillator.

As shown in Figure 6, the VCO Schematic, a current proportional to the input signal is generated by transistor matrix Q6, Q7, Q8 and Q9. An examination of the circuit will show that a change in the input modulating signal results in an increase in current supplied by Q8 and Q9, for instance, to the CR7 - 10 diode quad network, while at the same time resulting in a decrease in current supplied by Q6 and Q7 to the CR3 - 6 diode quad network. The resulting change in the apparent impedance of the divider network results in an output voltage proportional to a modulating signal. This voltage is converted to a current source in the modulation amplifier and is applied to the feedback junction of the first oscillator section. As noted previously, the introducing of a current at this junction results in a center frequency shift and thus modulation is accomplished. For a detailed analysis of the diode quad modulator/multiplier, refer to Appendix C.

Automatic gain control is accomplished by varying the resistance in the feedback loop of the second stage of the oscillator. This resistance is varied by changing the gate potential on field effect transistor Q32. The AGC amplifier compares

FOLDOUT FRAME 2

REVISIONS							
DISPOSITION CODE: 1 MAY BE REWORKED 2 CANNOT BE REWRK. 3 RECORD CHANGE 4 NEW SHOP PRACTICE 5 PARTS MADE OK							
REV SYM	WORD CODE	DESCRIPTION	MFG EFF	DISP CODE PART	DISP CODE ASSY	APPROVAL & DATE
2		EXPERIMENTAL RELEASE CHANGED CIRCUIT AND INCORP. EO 725 & 727				18 Dec 65
3		INCORP EO'S 000810 000810-A				1/11/66 1/24/66
4		INCORP EC 000823				1/27/66
5		INCORP. EO 000074 000851				4-6-66

FOLDOUT FRAME 1

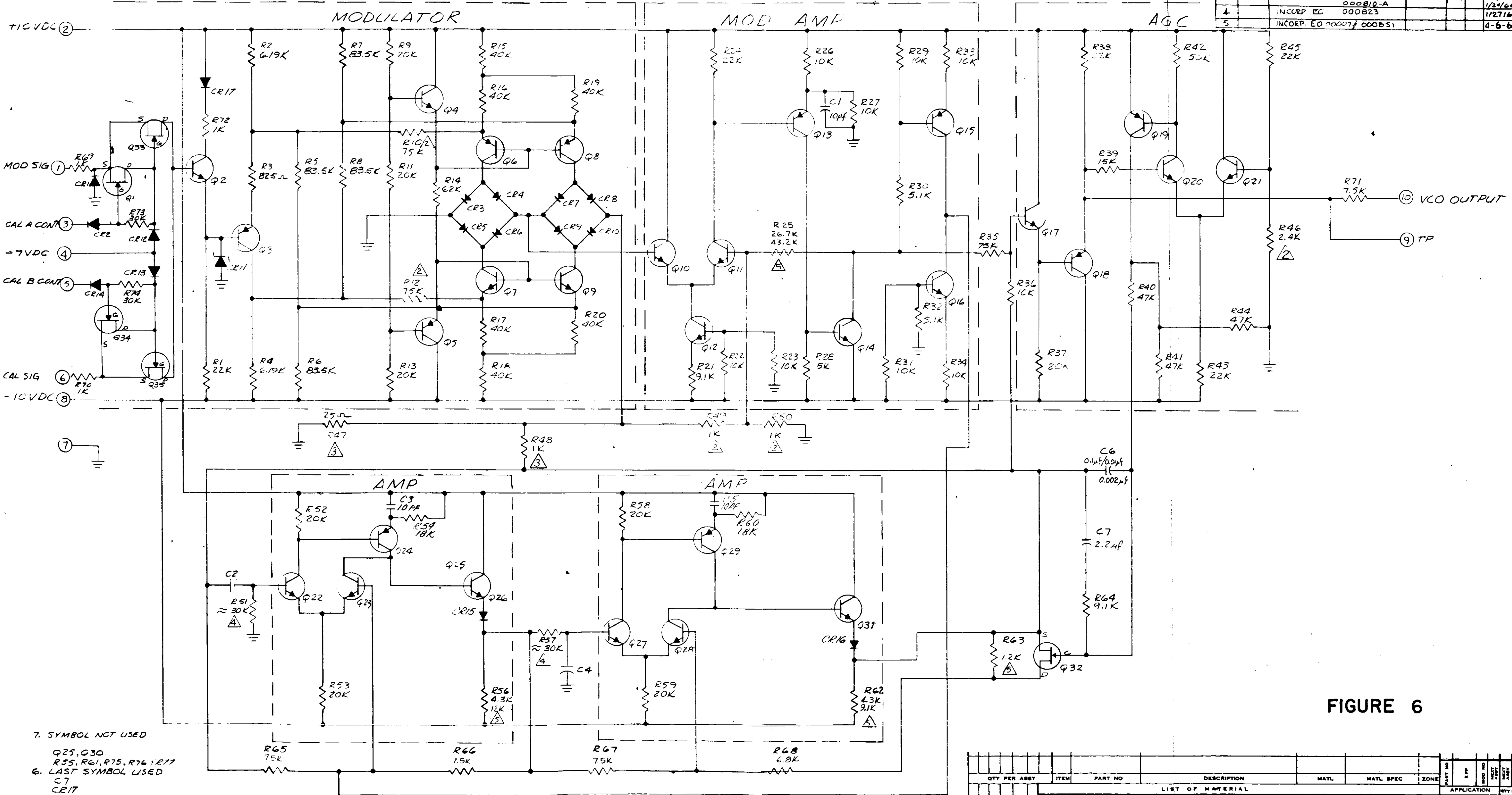


FIGURE 6

7. SYMBOL NOT USED
Q25, Q30
R55, R61, R75, R76 & R77
6. LAST SYMBOL USED
C7
CR17
Q35
R74
5. 2 VALUE SELECT RESISTORS
4. RESISTANCE & TC SELECTED & COMP
3. TC COMPENSATED
2. TEST SELECT
1. REF PARTS LIST 103865
NOTE: UNLESS OTHERWISE SPECIFIED

QTY PER ASSY	ITEM	PART NO	DESCRIPTION	MATL	MATL SPEC	ZONE
		LIST OF MATERIAL				

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: .XX = ± .03 .XXX = ± .010 X° - 0° ± 30' WEIGHT IS IN LBS & TENTHS ALL FINISHED SURFACES 125/ PER MIL-STD-10

MFR PER SPEC

TOLERANCE SYMBOLS PER MIL-STD-8 ELECTRICAL SYMBOLS PER MIL-STD-15 MECHANICAL SYMBOLS PER MIL-STD-17, WELDING SYMBOLS PER JAN-STD-19

DWG SIZE D

TITLE: SCHEMATIC VOLTAGE CONTROLLED OSCILLATOR

Spacelabs, Inc.
15521 LANARK ST.
VAN NUYS, CALIFORNIA

DWG NO XX 103864 REV 5

SHEET 1 OF 1

Frequency compensation is introduced by means of R4 and C1 which constitutes the feedback network for the mixing amplifier. The output of the amplifier is capacitively coupled by C2 to a balanced driver transformer.

Pre-emphasis Module

Pre-emphasis module contains the networks which provide signal pre-emphasis which is required before the signal is delivered to the composite signal amplifier.

The transformer output of the mixer amplifier is located in the pre-emphasis module and supplies the drive signal to the pre-emphasis networks. As shown in the schematic drawing, Figure 7, resistors R1, R2 and R3 are critical and are selected at final assembly.

Calibration and Regulator Module

Drawing 103873, Figure 9, is the schematic for the power regulators and the precision calibration source.

The regulators which receive $\pm$ 12 volts from the power supply module are identical high gain regulators and provide the system output voltages as required. These regulators operate in the series regulation mode and are designed to provide the required system power and stability and to maintain power dissipation at a minimum level.

The calibration voltage is generated by the regulating circuit shown on the bottom section of the drawing. This is a highly stable 5-volt precision source

FOLDOUT FRAME 1

FOLDOUT FRAME 2

REVISIONS						
DISPOSITION CODE: 1 MAY BE REWORKED 2 CANNOT BE REWKD. 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OK						
REV SYM	WORD CODE	DESCRIPTION	MFG EFF	DISP CODE PART	ASSY	APPROVAL & DATE
		CONTROLLED RELEASE				11/17/65
2		REVISED PER EO 00040				5/4/66

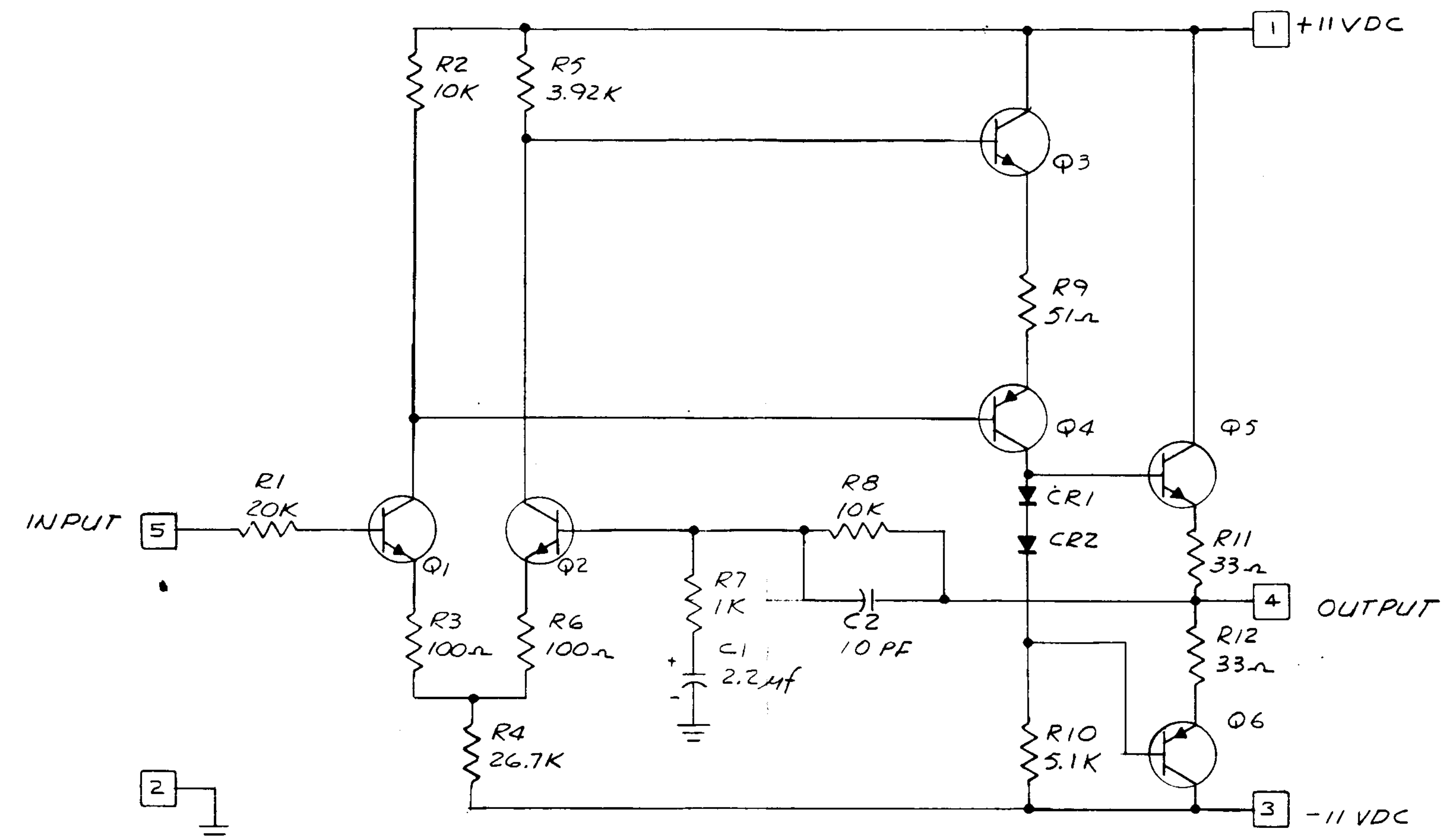


FIGURE 7

2. REF OUTLINE DWG 103869

1. REF PARTS LIST 103868

NOTE: UNLESS OTHERWISE SPECIFIED

3/65 DIETERICH-POST CLEARPRINT 1020-8

QTY PER ASSY	ITEM	PART NO	DESCRIPTION	MATL	MATL SPEC	ZONE

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: .XX = ± .03 .XXX = ± .010 X° = 0° ± 30' WEIGHT IS IN LBS & TENTHS ALL FINISHED SURFACES 125 √ PER MIL-STD-10

MFR PER SPEC

TOLERANCE SYMBOLS PER MIL-STD-8 ELECTRICAL SYMBOLS PER MIL-STD-15 MECHANICAL SYMBOLS PER MIL-STD-17 WELDING SYMBOLS PER JAN-STD-19

CALCULATED WT LB

103867

PART NO

REFERENCE TO SIMILAR DWG

DWG SIZE C

DRAFT	[signature]	10/31/65
DESIGNER		
STRESS & WEIGHT		
CHECKER		
DESIGN ENG	[signature]	11/17/65
MFG ENG		
STDS ENG		
PROJ ENG	[signature]	11-17-65

TITLE SCHEMATIC CSA AMPLIFIER

LAYOUT — RELEASE DATE

SCALE — WT ACT — LB WT CALC — LB

Spacelabs, Inc.
15521 LANARK ST.
VAN NUYS, CALIFORNIA

DWG NO XX103867 REV 2

SHEET 1 OF 1

PART NO	E FF	MOD NO	NEXT ASSY	NEXT ASSY	FINAL ASSY
APPLICATION					QTY REQ

FOLDOUT FRAME 1

FOLDOUT FRAME 2

REVISIONS						
DISPOSITION CODE: 1 MAY BE REWORKED 2 CANNOT BE REWKD. 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OK						
REV SYM	WORD CODE	DESCRIPTION	MFG EFF	DISP CODE PART	DISP CODE ASSY	APPROVAL & DATE
		CONTROLLED RELEASE				11/16/65

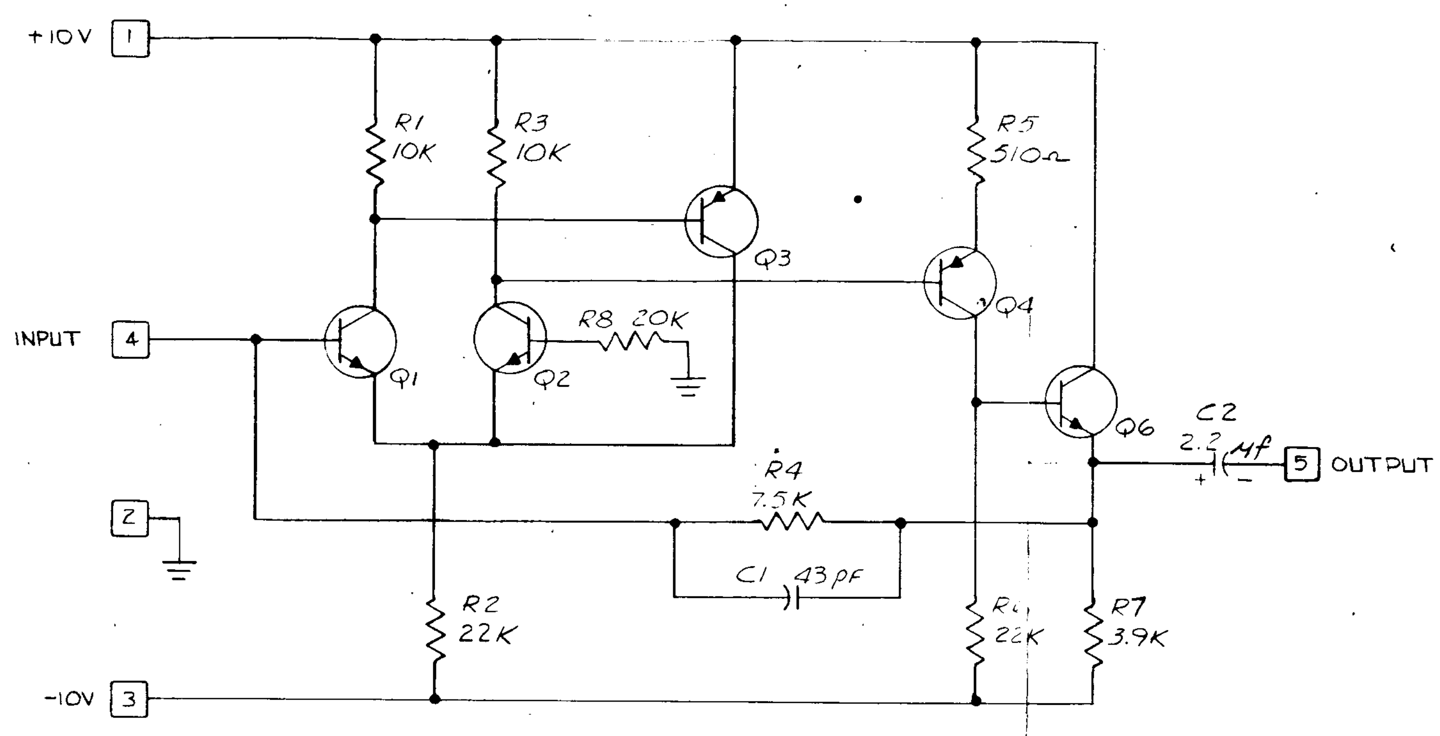


FIGURE 8

2 REF OUTLINE DWG 103872

1 REF PARTS LIST 103871

NOTE: UNLESS OTHERWISE SPECIFIED

QTY PER ASSY	ITEM	PART NO	DESCRIPTION	MATL	MATL SPEC	ZONE
			LIST OF MATERIAL			

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: .XX — ± .03 .XXX — ± .010 X° — 0' ± 30' WEIGHT IS IN LBS & TENTHS ALL FINISHED SURFACES 125√ PER MIL-STD-10

MFR PER SPEC

TOLERANCE SYMBOLS PER MIL-STD-8 ELECTRICAL SYMBOLS PER MIL-STD-15 MECHANICAL SYMBOLS PER MIL-STD-17 WELDING SYMBOLS PER JAN-STD-19

CALCULATED WT LB

PART NO 103870

REFERENCE TO SIMILAR DWG

DWG SIZE C

DRAFT	Conway	16Nov65
DESIGNER		
STRESS & WEIGHT		
CHECKER		
DESIGN ENG	[illegible]	11/16/65
MFG ENG		
STDS ENG		
PROJ ENG	[illegible]	11-16-65

TITLE SCHEMATIC MIXER AMPLIFIER

Spacelabs, Inc.
15521 LANARK ST., VAN NUYS, CALIFORNIA

DWG NO XX103870 REV 2

LAYOUT — RELEASE DATE —

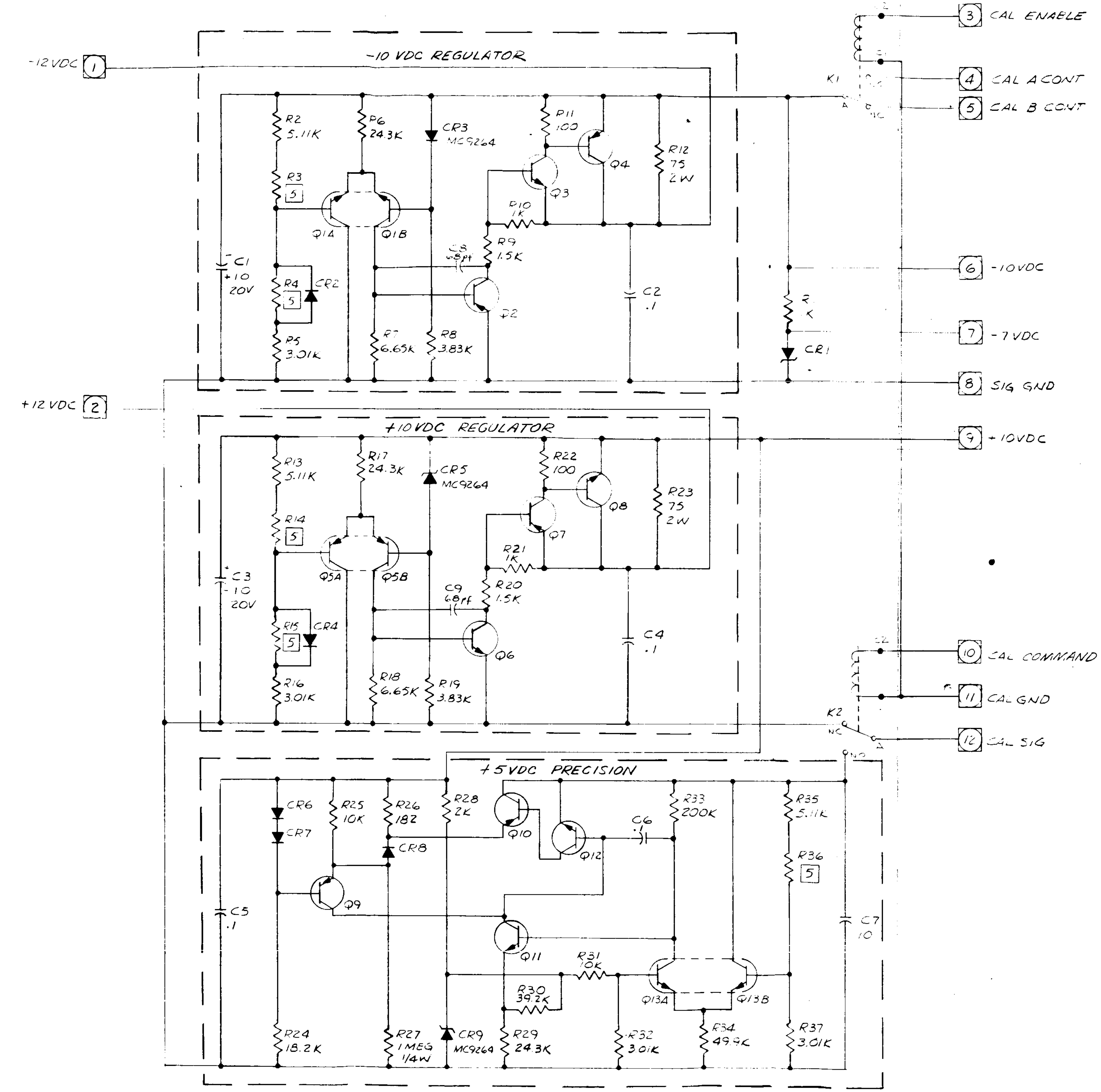
SCALE — WT ACT — LB WT CALC — LB SHEET 1 OF 1

APPLICATION: PART NO | E FF | MOC NO | NEXT ASSY | NEXT ASSY | FINAL ASSY | QTY REQ

3/65 DIETERICH-POST CLEARPRINT 1020-8

FOLDOUT FRAME 1

FOLDOUT FRAME 2



REVISIONS					
REV LTR	WORD CODE	DESCRIPTION	MFG EFF	DISP CODE PART / ASSY	APPROVAL & DATE
		CONTROLLED RELEASE			4/4/66

NOTES:

1. ALL RESISTANCE VALUES IN OHMS ±5% . 1/4 W
2. ALL CAPACITANCE VALUES IN MICROFARADS ± 10%. VDC
3. FOR ASSEMBLY SEE DRAWING 103875
4. FOR PARTS LIST SEE
5. RESISTOR VALUE TO BE SELECTED
6. HIGHEST USED REFERENCE DESIGNATIONS C9, CR9, K2, Q13, R37
7. REFERENCE DESIGNATIONS NOT USED

FIGURE 9

SCHEMATIC CALIBRATE & REGULATOR

Spacelabs, Inc.
15521 LANARK ST
VAN NUYS, CALIFORNIA

DWG NO XY103873 REV 2 SHEET 1 OF 1

DWG SIZE D

the amplitude of the output signal with a reference voltage and supplies a pulse of current by means of Q19 to the RC integrating network consisting of C6, C7 and R64. The effect on center frequency of varying the resistance in this feedback path has been analyzed and is included in Appendix D. The result of this analysis indicates that the percent change in center frequency is proportional to the square root of the percent change in this feedback path. Since the percent deviation in the feedback resistance required to maintain amplitude stability is small, the effect on oscillator center frequency can be neglected.

Composite Signal Amplifier

The design of the composite signal amplifier is basically fairly straightforward, and is rather a universal approach to amplifier design. However, it incorporates those features which are specifically required by the overall system.

The circuit, Figure 7, consists of a high gain amplifier and employs a differential input stage. A feedback network which provides the necessary bandpass characteristics is comprised of R7, R8, C1 and C2. A portion of the output voltage selected by this feedback network is supplied to one of the differential amplifier input terminals as standard operation amplifier practice.

The output circuit consisting of Q5 and Q6 and associated components provides a bilateral low impedance output drive signal.

Mixer Amplifier

The mixer amplifier, Figure 8, is a high gain amplifier configured to operate as an operational summing amplifier.

employing temperature-compensated components where required to insure calibration accuracy. This voltage is applied through appropriate relays to the input of the voltage controlled oscillators as dictated by the calibrate logic.

Power Supply

The power supply module, Figure 10, performs various functions. It consists of a switching type preregulator followed by a power inverter which supplies four separate output circuits. Each composite signal amplifier is supplied with a $\pm$ 11 volts from an individual isolated supply. Power regulation is accomplished by use of Zener diodes.

The fourth output is an unregulated $\pm$ 12 volts to the power regulators located in the calibrate and regulate module. The system requirement that each composite signal amplifier be isolated from each other and from the rest of the system necessitates the individual power supplies just described.

The power inverter section of the power supply consists of the power output section comprised of Q7 and Q8, T3, and associated circuit components. The drive for the output stage is coupled through transformer T2 to the bases of the output power transistors from the astable drive circuit comprised of Q5, Q6, and associated components.

This particular approach was employed to improve the overall efficiency of the power supply. A typical power inverter, where astable operation in a simple stage is accomplished by means of positive feedback windings to the

FOLDOUT FRAME 1

FOLDOUT FRAME 2

REVISIONS						
DISPOSITION CODE: 1 MAY BE REWORKED 2 CANNOT BE REWRKD 3 RECORD CHANGE 4 NOW SHOP PRACTICE 5 PARTS MADE OR						
REV SYM	WORD CODE	DESCRIPTION	MFG EFF	DISP CODE PART	DISP CODE ASSY	APPROVAL & DATE
		CONTROLLED RELEASE				3/23/66

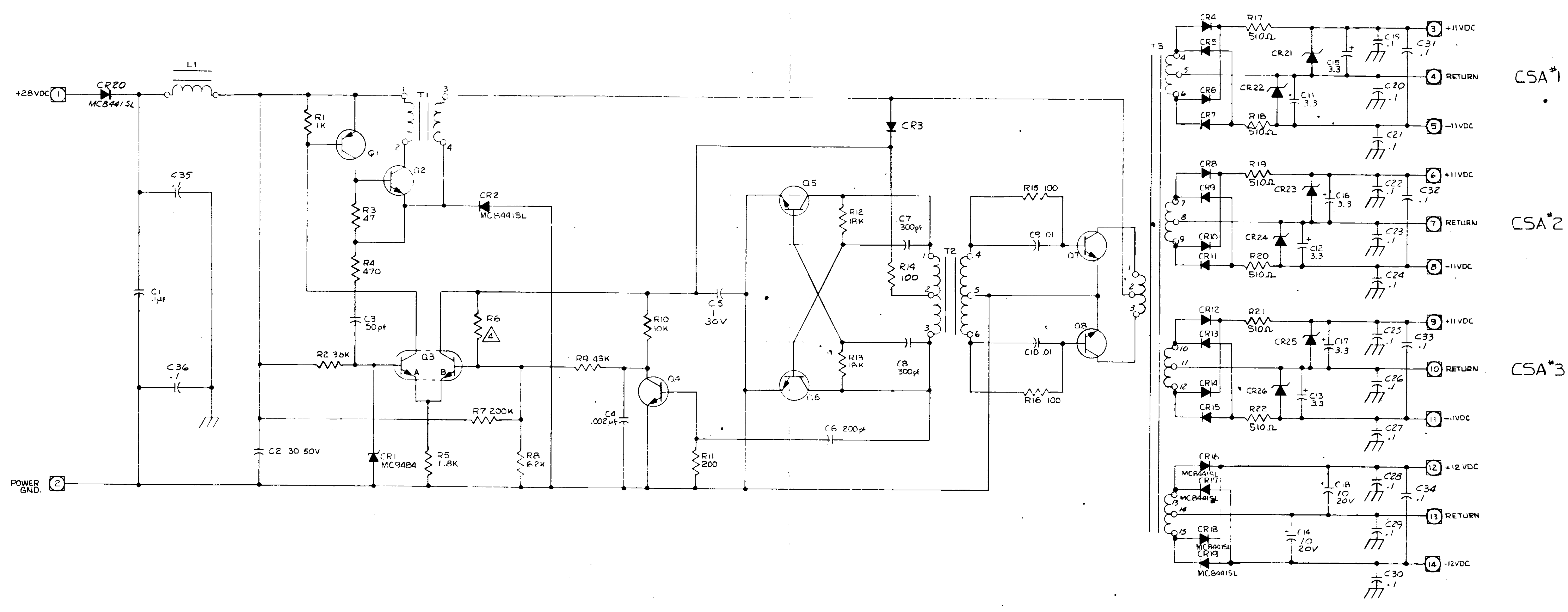


FIGURE 10

NOTE: UNLESS OTHERWISE SPECIFIED
1. ALL RESISTOR VALUES ARE IN OHMS
2. ALL CAPACITOR VALUES ARE IN MICROFARADS
3. ALL DIODES ARE MC3483 EXCEPT AS NOTED
4. TO BE SELECTED

NOT USED	LAST USED
	C36
	CR20
	Q8
	R22

TITLE	SCHEMATIC POWER SUPPLY
	Spacelabs, Inc. 15521 LANARK ST. VAN NUYS, CALIFORNIA
DWG NO	XX103876
REV	3
SHEET	1 OF 1
DWG SIZE	D
DRAFT	Blommendahl 2-21-66
CHECKER	Conway 3-1-66
PROJ ENG	3-1-66

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: XX = ± .02 XXX = ± .010 ∠ ± 30' WEIGHT IS IN LBS & TENTHS ALL FINISHED SURFACES 125/ PER MIL-STD-10

MFR PER SPEC

TOLERANCE SYMBOLS PER MIL-STD-8 ELECTRICAL SYMBOLS PER MIL-STD-15 MECHANICAL SYMBOLS PER MIL-STD-17 WELDING SYMBOLS PER JAN-STD-19

QTY PER ASSY | ITEM | PART NO | DESCRIPTION | MATL | MATL SPEC | ZONE

LIST OF MATERIAL

APPLICATION

1/65 DIETERICH-POST CLEARPRINT 1020-4

drive transistors, has the inherent disadvantage that saturation of the output transformer is necessary to effect switching. The resultant power dissipation, not only in the power transformer but the drive transistors, while tolerable in typical applications, resulted in an intolerable predicted temperature rise. In this particular design, transformer T2 is allowed to saturate, and since it is operating at a much lower power level, the overall power dissipation is reduced.

The switching regulator consists of Q1, Q2, Q3 and Q4. Q4 operates as a switch and drives its input signal from the astable drive circuit. On each alternate cycle, Q4 is switched ON and capacitor C4 is discharged. During the other half of each cycle, Q4 is switched OFF and C4 charges through R10. The time required for the voltage across C4 to reach a predetermined level is determined by the applied voltage. This is the same applied voltage as that which powers the driver and output stage. When the voltage across C4 exceeds the reference voltage comparator Q3, transistor Q1 is turned OFF and as a consequence transistors Q1 and Q2 are switched OFF. Feedback through R4 and C3 provide the regenerative effect necessary to insure fast switching rates. At this point the secondary of T1, which is the inductor in a typical switching regulator, supplies the necessary current to the output due to the stored energy. The secondary of T1 supplies the necessary collector voltage to Q2 for proper operation of the circuit.

In summary, the ON-OFF cycle of the switching preregulator is determined by the charging rate of R10 and C4 and the applied output voltage.

An input low pass filter consisting of C1, L1 and C2 provides the necessary attenuation of line transients and conducted interference to insure noise-free power regulation.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The magnitude of the individual problems, which combined during the course of the program to warrant discontinuation of the development effort, were unfortunately not anticipated during the conceptual stages of the system philosophy reflected in the proposal. Although many technical problems which were encountered were ultimately solved and were not in themselves responsible for discontinuation of the approach, the fact remains that the extent of the difficulties and the effort required to solve them were out of proportion with that expected and how they reflected in the overall contracted effort.

The technical problems encountered in the modulator for the Twin-Tee oscillator were of sufficient magnitude to require a change in the basic concept of the VCO in that the concept proposed for the VCO represented a major specific feature of the overall system. The abandonment of the concept represented a major program redirection.

The voltage controlled oscillator which was ultimately developed and released for microcircuit fabrication did, in fact, fulfill the requirements of the Contract Statement of Work, and in itself represented a new approach to this component of FM Telemetry Systems. It must be concluded, then, that development of the VCO was successful.

The remainder of the system components, although requiring state-of-the-art design and development techniques did not constitute in the agregate the technological problem of the VCO. These components were not responsible for the ultimate discontinuation of the program effort. Although some of the final details in certain of the system components had not been finally worked out, this was not due to technical problems; rather it was the result of delayed scheduled completion requirements resulting from the major difficulties and resultant program delays for which the VCO development effort was responsible.

The major problem which was ultimately responsible for discontinuing the effort was state-of-the-art limitations in microcircuit technology. The problem of manufacturing a hybrid microcircuit in the space available, together with the individual component requirements such as tolerances and temperature coefficients and the overall complexity of the VCO, when combined resulted in a requirement of such magnitude that the probability of success was extremely low.

Although the contract objectives were not specifically accomplished, a change in the technical scope was necessary in order to ultimately complete the effort. The results of the initial program effort indicate that constructive work was done, and that a net gain in technology was realized. The work that was accomplished during the initial phase of this program can, and should, provide the foundation for continued work in this area.

Recommendations

Performance of the VCO developed under this contract represents an advance in the state-of-the-art. This improved performance, the fact that the approach is novel, and the fact that considerable work has been expended in this development are sufficient reason to justify a recommendation that the Voltage Controlled Oscillator ultimately be developed through the microcircuit packaging stage. In view of the fact that there are considerable technical difficulties to overcome, it might be well to consider further development as an individual effort.

A considerable amount of effort was expended on the environmental and mechanical analysis of the overall system package. For the ultimately selected materials along with other materials initially considered is a rather thorough mathematical prediction of package performance under specified stress conditions. It is felt that this information should be of value in any subsequent work that may be done on this particular system and that it should provide the basis for a reasonable judgment of the expected behavior of similar packages in similar environments. Of particular interest in this analysis is the predicted stresses and resultant strains on module leads at the interface with the master interconnection board under various environmental conditions.

APPENDIX A

SYSTEM DESCRIPTION

SONEX, INC. CONFIGURATION

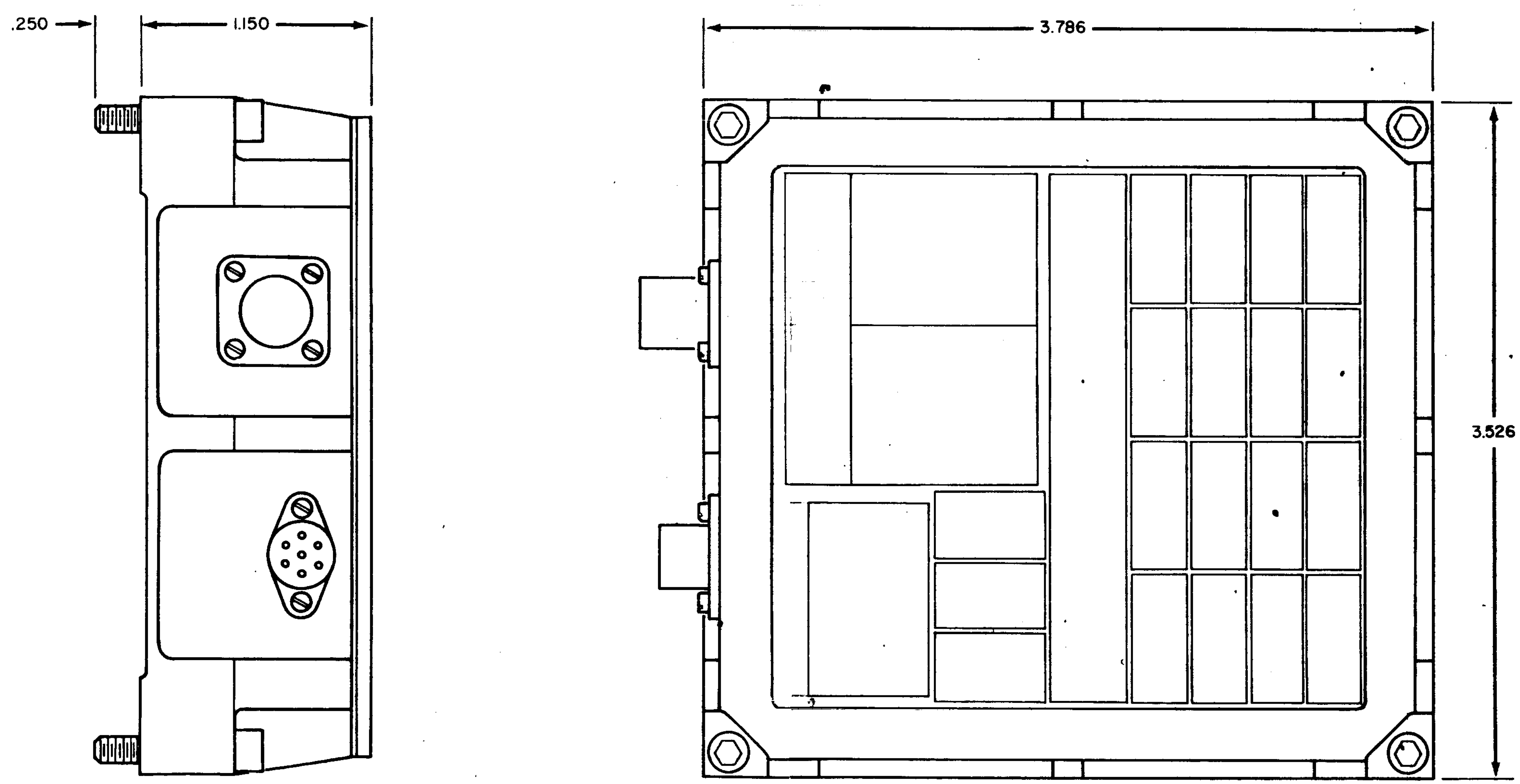
SYSTEM DESCRIPTION

SONEX, INC. CONFIGURATION

The final system delivered to NASA is generally defined in Figures 1 and 2. Due to the proprietary nature of the system developed by Sonex, Inc., a detailed description cannot be provided as a part of this report. The detailed system description will be directly provided to NASA by Sonex, Inc.

FOLDOUT FRAME 1

FOLDOUT FRAME 2



OUTLINE
16 CHANNEL
TELEMETRY
SYSTEM

FIGURE 1

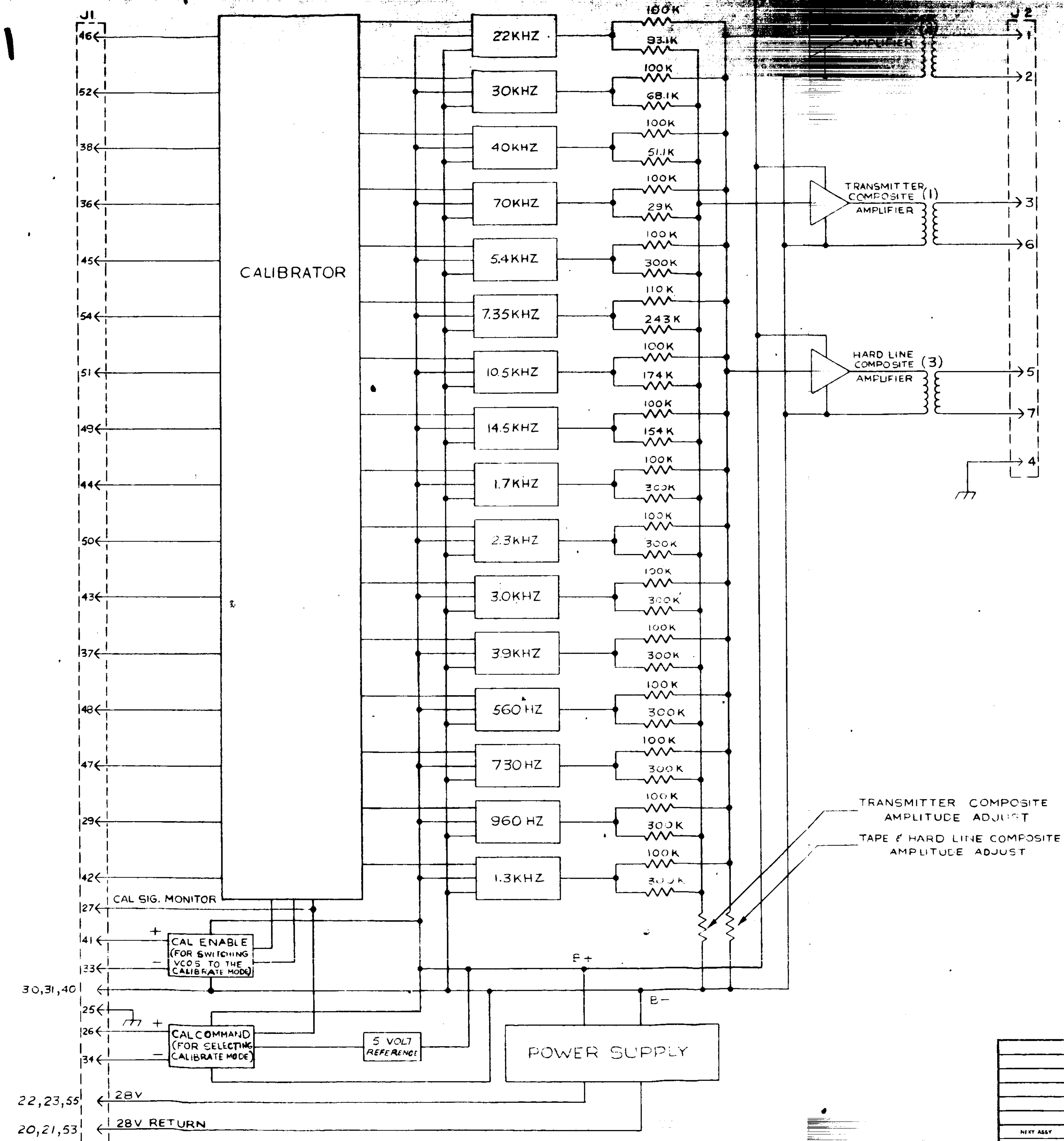


FIGURE 2

TITLE	BLOCK DIAGRAM 16 CHANNEL TELEMETRY SYSTEM
	Sonex PHILADELPHIA, PA
DWG SIZE	D
DRAWING NUMBER	SK03100-011
	DO NOT SCALE DWG
	APPLICATION
	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ON FRACTIONS DECIMALS ANGLES

APPENDIX B

APPENDIX B

Appendix B consists of two sections. Section B-1 lists the Engineering Drawings for the Spacelabs' 16-Channel FM Telemetry System which was ultimately discontinued due to technical difficulties encountered in the reduction of the system to microcircuit hardware.

Section B-2 consists of a compilation of system and component specifications.

B-1 ENGINEERING DRAWINGS

Systems Drawings

	Drawing No.	Title
1.	104100	16-Channel Assembly
2.	P/L 104100	16-Channel Assembly Parts List
3.	103987	Wiring Diagram
4.	104358	Board, Subassembly
5.	104368	Insulator
6.	104099	Board
7.	104367	Board Marking
8.	104098	Artwork, Board
9.	104532	Connector Assembly
10.	104533	Collar, Connector
11.	104359	Cable Assembly 1
12.	104356	Cable Assembly 3
13.	104363	Artwork Cable
14.	104104	Housing
15.	104105	Plate, Base
16.	104370	Standoff
17.	104110	Nameplate
18.	104369	Spacer
19.	104355	Outline
20.	104341	Test Plan
21.	104344*	Performance Requirements
22.	104345*	Acceptance Test Requirements

Composite Signal Amplifier Drawings

1.	103867	Schematic
2.	103868	Parts List
3.	103869	Outline Drawing
4.	104107	Case
5.	104319	Performance Requirement
6.	104287	Acceptance Test Requirement
7.	*	Acceptance Test Procedure
8.	*	Data Sheet, Acceptance Test Procedure
9.	104330 *	Test Set-up

*Indicates Document not Drawn or Written

Power Supply Drawings

1.	103867	Schematic
2.	104108	Assembly
3.	P/L 104108	Parts List
4.	103878	Case
5.	104357	Component Parts Board
6.	104360	Header
7.	104361	Artwork, Header
8.	104343	Performance Requirement
9.	*	Acceptance Test Requirement
10.	*	Acceptance Test Procedure
11.	*	Data Sheet, Acceptance Test Procedure
12.	*	Acceptance Test Set-up

*Indicates Document not Drawn or Written

Calibrate/Regulate Drawings

1.	103873	Schematic
2.	103875	Parts List
3.	103875	Assembly
4.	104362	Components Parts Board
5.	104374	Header
6.	*	Acceptance Test Requirement
7.	*	Acceptance Test Procedure
8.	*	Data Sheet, Acceptance Test Procedure
9.	*	Acceptance Test Set-up
10.	104342 *	Performance Requirement

*Indicates Document not Drawn or Written

Systems Drawings (Cont'd.)

23.		*	Acceptance Test Procedure
24.		*	Data Sheet, Acceptance Test Procedure
25.	104347	*	Qualification Test Procedure
26.	104348	*	Data Sheet, Qualification Test Procedure
27.	102556		Interference Control Plan
28.			Acceptance Test Set-up

* Indicates Document not Drawn or Written.

Voltage Controlled Oscillator Drawings

1.	103864	Schematic
2.	103865	Parts List
3.	103866	Outline Drawing
4.	104106	Case
5.	103903	Test Plan
6.	103905	Performance Requirement
7.	104289	Acceptance Test Requirement
8.	104338	Acceptance Test Procedure
9.	104339	Data Sheet, Acceptance Test Procedure
10.	103904	Specification for Resistor
11.	104318	Specification for VCO, Determining Capacitor
12.	104340	Acceptance Test Unit
13.	1008319	Final Acceptance Test Procedure
14.		Acceptance Test Set-up

Mixer Drawings

1.	103870		Schematic
2.	103871		Parts List
3.	103872		Outline Drawing
4.	104317		Performance Requirement
5.	104288		Acceptance Test Requirement
6.		*	Acceptance Test Procedure
7.		*	Data Sheet, Acceptance Test Procedure
8.	104107		Case
9.	104153		Test Set-up

* Indicates Document not Drawn or Written

Pre-Emphasis Network Drawings

1.	104365	Assembly
2.	104364	Component Parts Board
3.	103867	Schematic
4.	104372	Header
5.	103877	Board, Terminal
6.	104371	Artwork, Board, Terminal
7.	P/L 104365	Parts List
8.		Performance Requirement

B-2 SYSTEM AND COMPONENT SPECIFICATIONS

	Drawing No.	Title
1.	604402*	Silicon Diode G. P., Specification for
2.	604403*	Silicon Diode L. L., Specification for
3.	602503*	Capacitor Ceramic, Specification for
4.	602010	Capacitor Tant, Specification for
5.	602011*	Capacitor $\pm$ 30 PP/°C, Specification for
6.	603506	Transistor NPN, Specification for
7.	603507	Transistor PNP, Specification for
8.	603508	Transistor NPN and PNP, Specification for
9.	603901	Transistor FET, Specification for
10.	605007*	Inductor LI, Specification for
11.	605008*	Transformer T1, Specification for
12.	605009*	Transformer T2, Specification for
13.	605010*	Transformer T3, Specification for
14.	*	Encapsulation, Specification for
15.	609001	Nickel Ribbon, Specification for
16.	609002	Wire, Nickel, Specification for
17	609017	Freezecoat, Specification for
18.	609018	Epoxy Hardener, Specification for
19.	609019	Epoxy Hardener, Specification for

*Indicated Document not Written

APPENDIX C

DIODE MODULATOR ANALYSIS

DIODE MODULATOR

ANALYSIS

The diode modulator is basically a voltage divider as shown in Figure 1. The resistors R_A and R_B are functions of current - the current being supplied, in the actual circuit (Figure 2), by a constant current source, the magnitude of which is proportional to the modulation voltage.

In the simplified circuit of Figure 1, assume:

$$R_A = \frac{K_1}{Im_1}$$

$$R_B = \frac{K_2}{Im_2}$$

and

$$Im_1 + Im_2 = \text{constant}$$

$$= Im_c$$

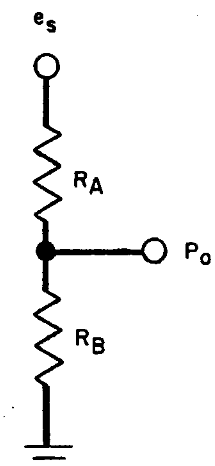


FIGURE 1.

$$e_o = \frac{e_s R_B}{R_A + R_B} = \frac{e_s \dfrac{K_2}{Im_2}}{\dfrac{K_1}{Im_1} + \dfrac{K_2}{Im_2}} \doteq \frac{e_s K' Im_2}{Im_c} \qquad (1)$$

The output voltage, e_o, is the product of the applied voltage e_s and the modulating current $Im_2 = K_m e_m$ then

$$e_o = K'' e_s e_m \qquad (2)$$

Figure 2 shows a diode network which serves as the voltage divider and the variable resistors R_A and R_B of Figure 1.

From the diode equation,

$$I = I_o \left(e^{\frac{E}{K}} - 1 \right)$$

$$E = KLn(I) - KLnI_o$$

and

$$dE = \frac{K}{I} \; dI$$

By definition

$$I_A = I_o + \Delta I$$

$$I_B = I_o - \Delta I$$

The diode current is

$$\frac{I_A - I_2}{2} \qquad \text{and}$$

$$\frac{IA + I2}{2} \qquad \text{for the}$$

upper section and

$$\frac{I_B - I_2}{2} \qquad \text{and}$$

$$\frac{I_B + I_2}{2} \qquad \text{for the lower section}$$

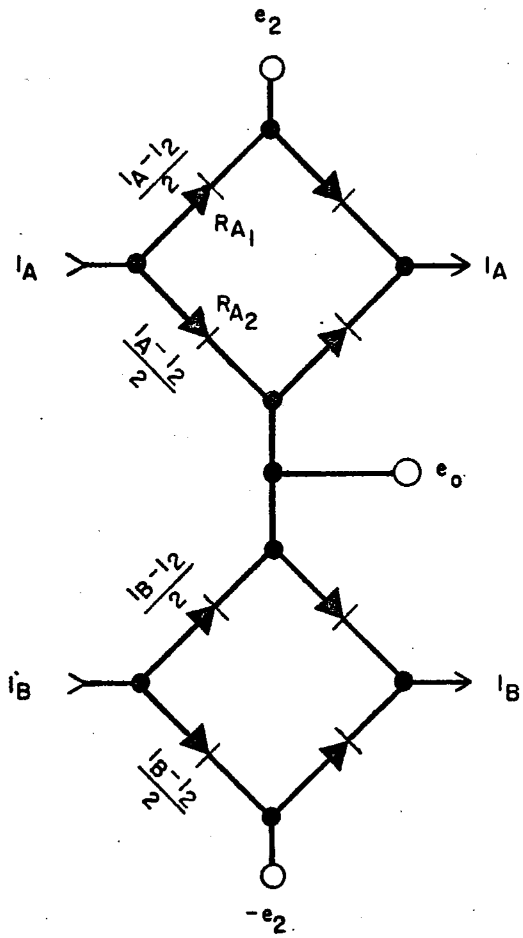


FIGURE 2.

Substitution into the diode equation yields,

$$2E_2 = -KLn\left(\frac{I_A - I_2}{2}\right) + KLn(I_o) + KLn\left(\frac{I_A + I_2}{2}\right) - KLn(I_o)$$

$$- KLn\left(\frac{I_B - I_2}{2}\right) + KLn(I_o) + KLn\left(\frac{I_B + I_2}{2}\right) - KLn(I_o)$$

From this equation the error term due to I_2 is derived and is:

$$I_2 = -\frac{(I_A + I_B)\left(1 + e^{\frac{2E_2}{K}}\right)}{2\left(1 - e^{\frac{2E_2}{K}}\right)} - \left\{\frac{(I_A + I_B)^2\left(1 + e^{\frac{2E_2}{K}}\right)^2}{4\left(1 - e^{\frac{2E_2}{K}}\right)^2} - I_A I_B\right\}^{1/2} \qquad (3)$$

The output voltage e_o is:

$$e_o = -KLn\left(\frac{I_B - I_2}{2}\right) + KLn(I_o) + KLn\left(\frac{I_B + I_2}{2}\right) - KLn(I_o) - E_2$$

or

$$e_o = KLn\left(\frac{I_B + I_2}{I_B - I_2}\right) - E_2 \qquad (4)$$

The incremental change is thus,

$$R_{A_1} = \frac{K}{\frac{I_A - I_2}{2}}$$

$$R_{A_2} = \frac{K}{\frac{I_A + I_2}{2}}$$

$$R_{A_1} + R_{A_2} = \frac{4KI_A}{I_A^2 - I_2^2}$$

For the R_A section then,

$$R_A = 1/2 \text{ Inc. } (R_{A_1} + R_{A_2}) = \frac{2K}{I_A - \frac{I_2^{\,2}}{I_A}}$$

Similarly

$$R_B = \frac{2K}{I_B - \frac{I_2^{\,2}}{I_B}}$$

For $\quad I_A = I_o + \Delta I$

$$\text{Inc. } R_A = \frac{2\ K}{I_o + \Delta I - \frac{I_2^{\,2}}{I_o + \Delta I} + K\ I_2^{\,2}}$$

For $\quad I_2 = 0$

$$\text{Inc. } R_A = \frac{2K}{I_o + \Delta I}$$

For E_2 small, the incremental values can be used.

for e_o using the incremental values, and ignoring I_2,

$$e_o = \frac{\Delta I}{I_o} \qquad (E_2)$$

for

$\Delta I \alpha e_m$

$e_o = K\ e_m\ (E_2)$

APPENDIX D

VCO TEST DATA

VCO TEST CIRCUIT

A. Breadboard Design

In fabricating the test breadboard, an attempt was made to simplify the test and calibration procedure in the production units. Accordingly, no matched transistors were employed in the unit. The diodes in the modulator were pruchased unmatched and a set selected in the laboratory on the basis of an approximately equal d.c. voltage drop at room temperature.

Also, the resistors in the two RC networks were not temperature compensated to the capacitors. Gross compensation was accomplished in the modulator. The uncompensated frequency drift was less than $\pm$ 1% of bandwidth.

Two temperature compensating resistors were therefore required. The first was utilized to stabilize center frequency. The second was used to stabilize bandwidth. The differences between the test breadboard and the prototype microcircuit VCO's may be summarized as follows:

Matched transistors were not used.

Matched diode quads were not purchased. Only nominal d.c. match at room temperature was employed.

RC combinations were not compensated per se.

"Balco" wire wound resistors, rather than film type, were employed for compensation.

Transistors Q17 and Q18 are included for convenience only. They provide a low impedance output for test purposes. Although they are included in the prototypes, they will be deleted in production units. Production VCO's will also employ $\pm$ 5 volts instead of $\pm$ 10 volts d.c.

B. Test Phase

Two sets of test data are included in the accompanying figures. Operation of the breadboard in its present form is in conformance with Figures 3 and 4. Figures 1 and 2 present the original test data evolving from breadboard tests, and are presented for reference.

The unit was assembled and tested for overall qualitative performance. The modulator feedback was then disconnected and the basic oscillator frequency adjusted to 3000 Hz (center frequency) by adjusting the resistor in the two RC combinations. The modulator was then connected and the frequency readjusted to center by adjusting a resistor (R49) in the modulator bridge. The bandwidth was then adjusted by resistors R10 and R12. The adjustments were relatively small increments. A temperature run was made from -40°C to +110°C. Four temperature cycles were made to stabilize the circuit, but no significant changes were noted. The temperature compensation resistors were then calculated, wound from Balco wire, and installed. The center frequency compensation was satisfactory, but an additional adjustment was made on bandwidth. The unit was then tested, and the results summarized in Figures 1 and 2.

Upon cleaning the boards, prior to placing the breadboard in the case, Murphy's Law was once more validated, and lead broke from one of the two precision capacitors. This occurred Wednesday p.m., and procuring additional capacitors was not practical on short notice. The encapsulation to the capacitor lead termination point was removed, and another lead gingerly soldered in place. However, the capacitor value was slightly changed, and the oscillator no longer performed within the $\pm$ 0.5% stability over the temperature range. The center frequency was readjusted, and bandwidth was recompensated with "Balco"

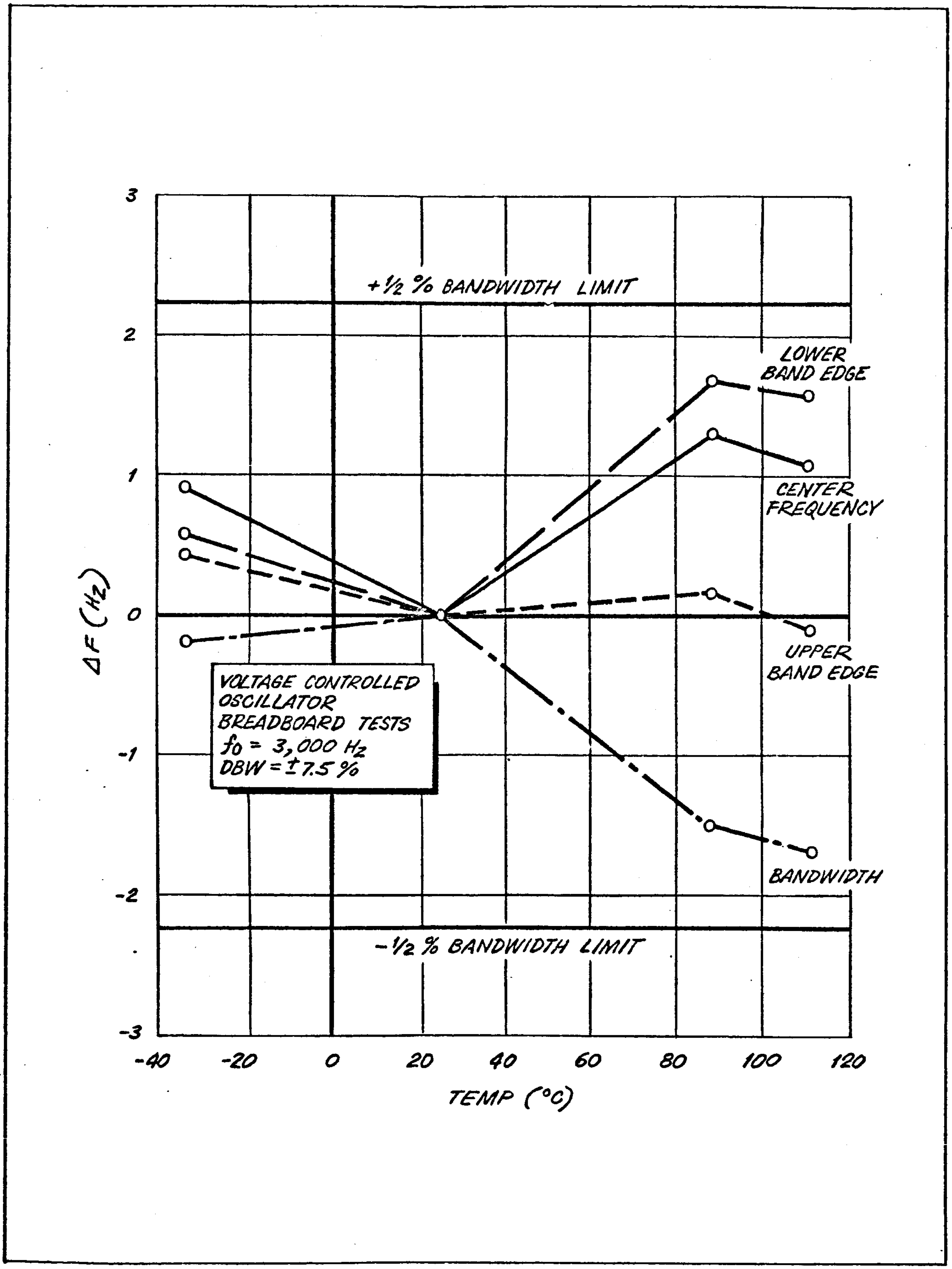

+1/2 % BANDWIDTH LIMIT
-1/2 % BANDWIDTH LIMIT
LOWER BAND EDGE
CENTER FREQUENCY
UPPER BAND EDGE
BANDWIDTH
VOLTAGE CONTROLLED OSCILLATOR BREADBOARD TESTS
f0 = 3,000 Hz
DBW = ±7.5 %
ΔF (Hz)
TEMP (°C)
3
2
1
0
-1
-2
-3
-40
-20
0
20
40
60
80
100
120

FIGURE 1

VOLTAGE CONTROLLED OSCILLATOR

BREADBOARD TESTS

TEMPERATURE TEST

Input	+5.00 V	+2.5 V	0.00 V	Ampl.	B.W. (Hz)
- 35°C	3226.0	3001.5	2776.1	+2%	449.9
+ 26°C	3225.6	3000.6	2775.5	-	450.1
+ 90°C	3225.8	3001.9	2777.2	-3%	448.6
+110°C	3225.5	3001.7	2777.1	-4%	448.4

Ampl. Mod. - Approximately 2% @ 5 x IRIG

LINEARITY, ROOM TEMPERATURE: Approximately 0.1%

LINEARITY (Approximately 110°C)

		Δf	Δf^2	Hz
5.00 V	3225.6	45.3	+0.48	
4.50 V	3180.3	44.9	+0.08	+0.56
4.00 V	3135.4	44.6	-0.22	+0.34
3.50 V	3090.8	44.5	-0.32	+0.02
3.00 V	3046.3	44.4	-0.42	-0.40
2.50 V	3001.9	44.4	-0.42	-0.82
2.00 V	2957.5	44.6	-0.22	-1.04
1.50 V	2912.9	44.7	-0.12	-1.16
1.00 V	2868.2	45.2	+0.38	-0.78
0.50 V	2823.0	45.6	+0.78	0
0.00 V	2777.4			

Maximum Deviation From Straight Line Joining End Points = 1.16 Hz

LINEARITY = 1.16/450 = 0.25%

Distortion: Nominally 0.1% Over Temperature and Bandwidth

FIGURE 2

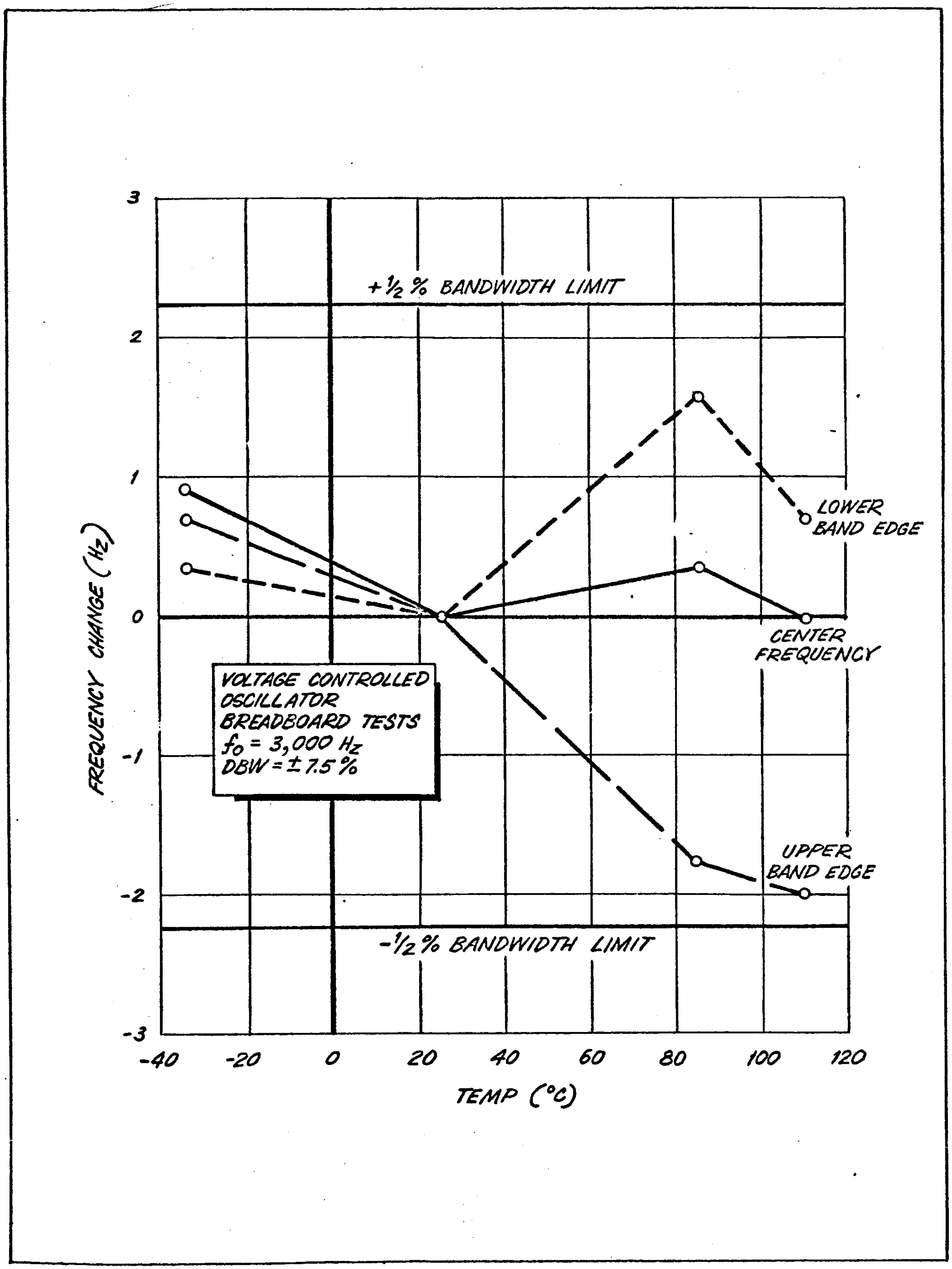

+½ % BANDWIDTH LIMIT
-½ % BANDWIDTH LIMIT
LOWER BAND EDGE
CENTER FREQUENCY
UPPER BAND EDGE
VOLTAGE CONTROLLED OSCILLATOR BREADBOARD TESTS
f_0 = 3,000 Hz
DBW = ± 7.5 %
FREQUENCY CHANGE (Hz)
3
2
1
0
-1
-2
-3
-40
-20
0
20
40
60
80
100
120
TEMP (°C)

FIGURE 3

VOLTAGE CONTROLLED OSCILLATOR

BREADBOARD TEST

TEMPERATURE TEST

Input	+5.00 V	2.50 V	0.00 V	B.W. (Hz)
- 35°C	3226.2	3000.5	2774.1	452.1
+ 24°C	3225.5	2999.6	2773.7	451.5
+ 85°C	3223.7	2999.9	2775.3	448.4
+110°C	3223.5	2999.5	2774.4	449.1

Amplitude: ± 5% Over Temperature Range

Amplitude Modulation: Approximately 2% @ 5 x IRIG

LINEARITY (ROOM TEMPERATURE)

Input Voltage	Frequency	Δf
5.003	3225.4	45.4
4.502	3180.0	45.1
4.002	3134.9	45.1
3.502	3084.8	45.1
3.001	3049.7	45.0
2.501	2999.7	44.9
2.000	2954.8	45.1
1.500	2909.7	45.1
1.000	2864.6	45.2
0.499	2819.4	45.4
0.000	2774.0	

B.W. = 457.4 Hz

Maximum Deviation From Line Through End Points = 0.32 Hz = 0.071% Linearity

Distortion = 0.10% Over Bandwidth

FIGURE 4

resistors on hand. Center frequency compensation was left as is. Performance of the unit, though not as good as originally achieved, is within the ± 0.5% stability and ± 0.25% linearity specification.

C. Results

The results suggest that ± 0.5% stability and ± 0.25% linearity can be achieved over the temperature range from -40°C to +110°C without necessitating matched transistors or temperature compensation in the RC networks. This not only simplifies test and calibration, but also reduces package size since the TC resistors are discrete components. One cannot base a decision of this importance on an isolated breadboard test. However, over the last six months, many such tests have been made, and results are repeatable.

One area which has received considerable attention, and has been discussed at great length, is the linearity aspect of performance. Linearities exceeding 0.1% have been achieved at all temperatures except those exceeding about 80°C. Linearity at 110°C is presently limited to 0.25%. This deterioration in linearity is the result of a "hook" at each end of the band at high temperature, as illustrated by the linearity data of Figure 2. We now feel that the source of this non-linearity has been discovered, and there is mathematical verification. Diode leakage at high temperature tends to effect sensitivity, and the effect is more pronounced at the band edges where the current through one of the diode quads is at a minimum. Tests are presently underway to verify this theory. If, in fact, this is the source, the linearity specification may be increased to ± 0.1 - 0.15%. If such is the case, we would appreciate the opportunity of updating the test circuit to the improved specification, and likewise improving overall frequency drift by the same token.

It is estimated (in Engineering) that one day would be required for the modification. Applying the standard correction factor results in a 10 day effort.

Unfortunately, no changes of the above nature are possible in the prototypes in consideration of schedule. However, these performance improvements can be readily incorporated in production units.